# INSTITUTO DE SISTEMAS OPTOELECTRÓNICOS Y MICROTECNOLOGÍA

**(INSTITUTE FOR SYSTEMS BASED ON OPTOELECTRONICS AND MICROTECHNOLOGY)**

# ACTIVITY REPORT

## 2002-2003

**UNIVERSIDAD POLITÉCNICA DE MADRID**

# Instituto de
# Sistemas Optotelectrónicos y Microtecnología

***(INSTITUTE FOR SYSTEMS BASED ON OPTOELECTRONICS AND MICROTECHNOLOGY)***

## Universidad Politécnica de Madrid

# Activity Report

# 2002-2003

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# PREFACE

*The Institute of Optoelectronics Systems and Microtechnology (ISOM), established in March 2000, is devoted to research and development activities in information and communication technologies, based on IIII-V semiconductors and magnetic materials. This report summarizes the technical and scientific activities carried out at ISOM in 2002-03. During this period, new members have joined the Institute, the processing facilities have been completed, and the activity in the field of low dimensional devices and nanostructures progressed with significant scientific contributions. The engineering and scientific activities of ISOM have been pursued in collaboration with Spanish industries and institutions, and with leading European and international research centers.*

*Research on semiconductor materials and devices at ISOM has been largely based on binary and ternary compounds containing nitrogen (Nitrides), leading to either wide or narrow bandgap heterostructures. These compounds have already shown quite interesting properties and scientific challenges, along with important applications. In the area of magnetic materials, research has been focused on nano and microstructured soft materials, multilayer microsystems and hybrid systems that may be used in multifunctional sensors. It is worth to mention the fruitful scientific interactions and collaborations established in this period between researchers in both fields of magnetic devices and semiconductors, leading to joint research proposals.*

*In 2003, ISOM has been very active in participating in a significant number of proposals to the VI Framework Program of the European Union. Two STREP projects on nanotechnology were granted, starting in January 2004, focused on each of the main research areas of ISOM. The ISOM strategy is to further promote research on nanostructures and nanoengineering, based, mainly, on Molecular Beam Epitaxy and on Electron Beam Lithography. ISOM wants to gather and to lead national efforts in nanoscience and nanoengineering.*

*This period has been quite successful, both in terms of relevant scientific publications and in financial support. I wish to mention here that at the end of 2003, with partial support form the Research Program of the Regional Government of Madrid, a new MBE system was commissioned. This new epitaxial growth facility will enlarge our research capabilities in the area of nano and microstructures.*

*In close relation with one of ISOM objectives, the cooperation with Spanish industries and institutions has been reinforced in this period. Direct contracts and joint projects funded by the Spanish Ministry of Science and Technology (PROFIT projects) have supported such cooperation. The cooperation with universities and research centers has continued to be a key priority for the Institute. Along this line, I would like to emphasize the association, agreed in this period, of ISOM to the CSIC-National Center of Microelectronics-Barcelona, that has boosted joint research activities between both institutions.*

*At the end of 2001, the Technology Center of ISOM was acknowledged as a Large Scientific Infrastructure (GIC) by the Spanish Ministry of Science and Technology, that we consider as a significant milestone for our objectives, that is, to offer processing technology and characterization services to external centers and industries. In the 2002-03 period, ISOM has restructured its facilities and trained the technical staff to implement such rol. As a first step along this line, a significant number of services have been already provided to external colleagues.*

*Finally, I wish to thank all ISOM scientific staff members and support personnel, as well as PhD students, for their commitment and continuous efforts through these years. Thanks also are given to the Electronic Engineering and Applied Physics Departments, to the ETSIT Director and Technical Office, and to the Rector of UPM for their continuous support and comprehension. Special credit has to be given to Pedro Sánchez, Mari Mar Sanz and Montse Juárez for their dedication to make this report to be born.*

*Madrid, June 2004*

*Elias Muñoz Merino*
*Director*

# *Activity Report 2002-2003*

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# 1. PRESENTATION

The *Instituto de Sistemas Optoelectrónicos y Microtecnología* (ISOM, Institute for Systems based on Optoelectronics and Microtechnology) is an interdepartmental research institution of the *Universidad Politécnica de Madrid* (UPM). ISOM was created on March 16th 2000 (BOCM March 28th 2000) as a result of the proposal presented by several research groups from the Departments of Electrical Engineering, Photonic Technology, Applied Physics to Information Technology and Applied Physics to Architecture and Environment.

The ISOM facilities are located in the basement of the *López Araujo* Building at the School of Telecommunication Engineering of UPM. These facilities include 400 m$^2$ cleanrooms (100-1000 class), and 300 m$^2$ of characterization and system development laboratories. In addition, there are areas devoted to Industrial Collaboration and Technology Transfer, as well as a specific office to manage the External Services. The centre is made up of a team of 35 researchers, 4 technicians and 1 administrative assistant. Its size, as well as its extensive experience in research during the last two decades, makes this team distinctively well suited for research and development activities. In fact, they have participated in numerous projects funded by the European Union.

ISOM received from *Comunidad Autónoma de Madrid* the equipment that had been previously donated by *Telefónica I+D*, which belonged to its former Centre for Optoelectronics. The technology processes available at ISOM allow the manufacture of materials, their technological processing, and the manufacture of integrated electronic, optoelectronic, optic and magnetic devices. At present, ISOM has the capability to develop and manufacture laser diodes for instrumentation, environment and optical communications; microwave transistors for high power and temperature applications; infrared photodetectors for civil and military applications; ultraviolet photodetectors for UV solar radiation monitoring and military applications; magnetic sensors for a wide range of applications, and SAW filters for RF and mobile communications.

Since April 2002 ISOM is recognised as one of the *Associated Units* of the CSIC (*Consejo Superior de Investigaciones Científicas*). The Cooperation Agreement with CSIC is a result of the close collaboration between ISOM and the IMB-CNM (*Instituto de Microtecnología de Barcelona del Centro Nacional de Microtecnología del CSIC*)

*The Centre for Technology of ISOM was awarded the recognition of "Gran Instalación Científica (GIC)" (Large Scientific Infrastructrue or Major Scientific Facility) by the Spanish GIC Committee, on November 2001*

# 2. OBJECTIVES

The goal of ISOM is to perform research in the fields of detection, processing, transmission and recording of information by means of Opto- and Micro-electronics. The transfer of the results to the industry is a goal as well. The training of innovating professionals will be accomplished through their participation in such research and development tasks.

ISOM seeks to be a technology research laboratory able to participate, under the most favourable conditions, in European projects. This participation ought to be as a centre of excellence, with the capabilities to perform tasks under equal conditions to those from similar centres in Europe.

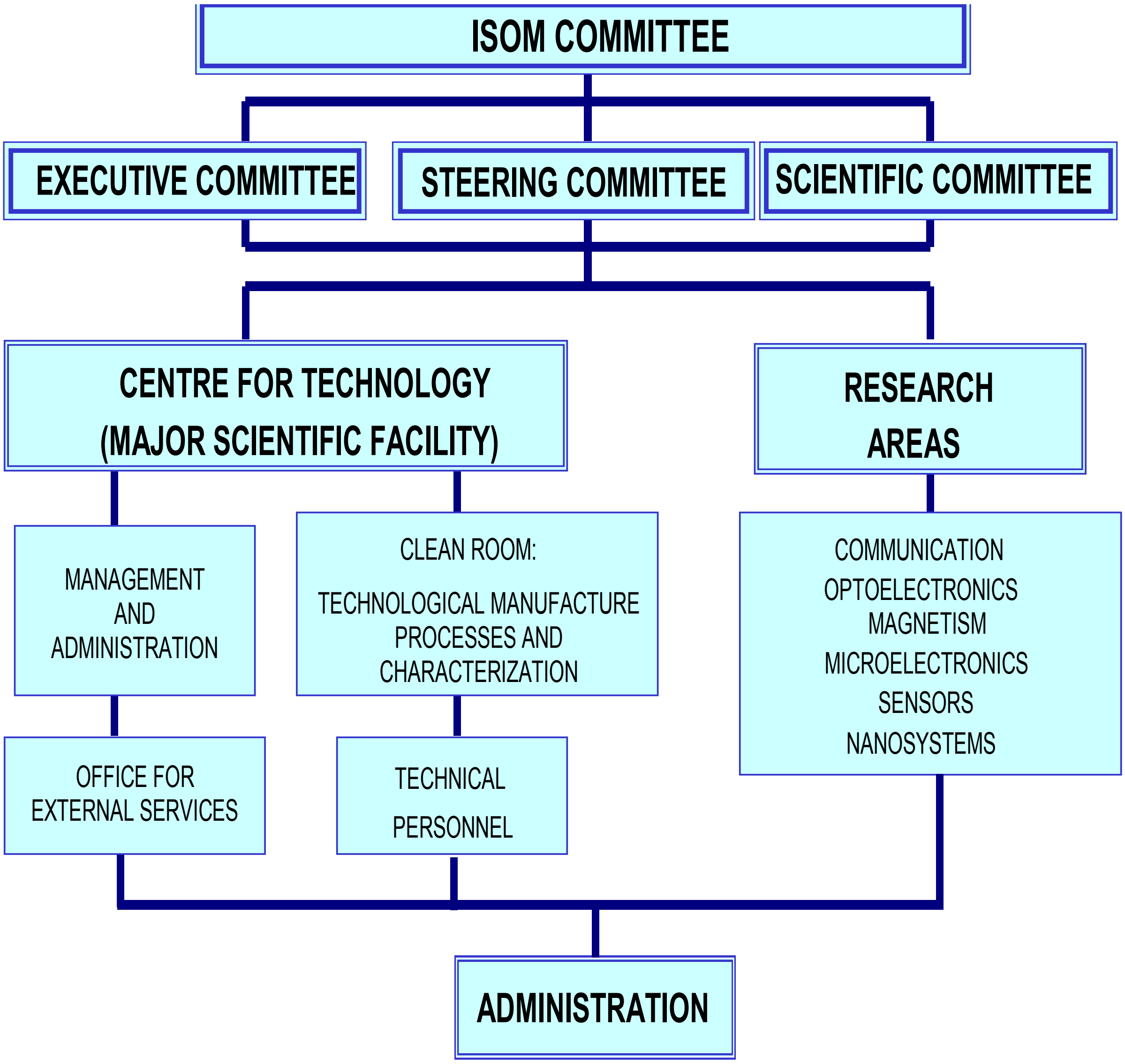
Three distinct features are characteristic of ISOM: 1) the availability of the required technology to be able to provide pre-industrial control and reproducibility, as well as technology transfer to industries; 2) the vocation to develop scientific and technological collaborations between industry and academic institutions; and 3) the wish to offer external services on characterization, quality control and reliability, in the framework of Optoelectronics and Technology for Communication and Information.

ISOM also offers collaboration schemes to suit industries' needs for usage of laboratory and cleanroom facilities during arranged periods of time. For that purpose, ISOM provides special rooms available to industries for R&D activities, assuring industrial and intellectual property protection. Moreover, ISOM intends to participate in the generation of spin-off's by means of temporary agreements on usage of space and technological equipment as well as human resources.

ISOM wants to highlight its desire to develop collaboration schemes with universities and research centres. In this case, the collaboration consists of training doctors, joint doctorate programmes, and the development of technology and research. Along this path, ISOM has already endorsed several cooperation agreements.

Finally, ISOM (through its Centre of Technology) wants to offer its services on technology and characterization to the scientific and technical community. Thus, it hopes to count on facilities promoted by UPM and other institutions, which could be useful to this community in the field of electronics, optoelectronics and communications (several high resolution microscopy techniques, materials analysis, characterization of components, modules and systems, packaging, noise, etc.).

# 3. ORGANIZATION CHART




## STAFF:

| | |
|---|---|
| **Director:** | Elías Muñoz Merino |
| **Vice-director:** | Pedro Sánchez Sánchez |
| **Administrator:** | Enrique Calleja Pardo |
| **Technical Coordinator:** | Claudio Aroca Hernández-Ros |
| **Secretary (and CT manager):** | Fernando Calle Gómez |

# 4. TECHNIQUES & EQUIPMENT

**Laboratories: 400 m$^2$ Clean Rooms**

**class 100**

***Photolithography***

**class 1000**

***Growth Systems***
***Processing Rooms***

**300 m$^2$ Characterization Rooms**

Photolithography room

## Growth Systems

2 MBE Systems for III-V (GaAs y GaN) semiconductors Growth

Sputtering System for Magnetic Materials

## Devices Processing Technology

Systems for:
Optical and Electronical Photolithography, Metal Evaporation, RTA, RIE, cutting, microsoldering…

Masks alignement and insolator for UV-Photolithography

Joule Metal Deposition Systems

High Precision Scriber

## Characterization

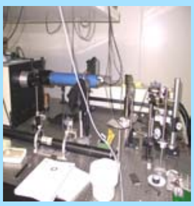
### Surface and Structural

Scanning Electron Microscope (SEM)

X-Ray Difractometer

### Optical

Optical Bench for UV-Luminescence



Optical Bench for IR-Luminescence Measurements

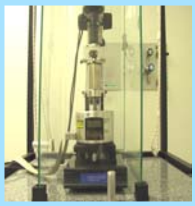
### Electrical

Probe station

Detectors characterization System

### Magnetic

Vibrating Sample Magnetometer (VSM)



Atomic Force Microscope (AFM) with magnetic tlp

## Growth and Manufacture Systems

- High precision Blade (3 systems) and Diamond Scriber
- Reactive Ion Etching (RIE)
- Electron Beam Nanolithography
- Magnetron Sputtering system (2 systems)
- Molecular Beam Epitaxy (MBE) (2 systems)
- Chemical Vapour Deposition (CVD and PE-CVD)
- UV Photolithography (resolution >1 μm ) (2 systems)
- Electron Beam Lithography (resolution >0.2 μm)
- Metal Deposition (Joule, e-beam) (5 systems)
- Electro-deposition
- Ultrasound and Thermocompression Microsoldering (2 systems)
- Standard and Rapid Thermal Annealing (RTA)

## Characterization Systems:

### A) Surface and Structural

- High Resolution X-Ray Difractometers (HR-XRD) (2 systems)
- Thickness Profiler (DekTak)
- Atomic Force Microscope (AFM)
- Scanning Electron Microscope (SEM) with EDAX

### B) Electrical and Magnetical

- Electrical and Optical Characterization Systems under Hydrostatic Pressure.
- Carrier Traps and Defect Analysis Techniques (DLTS, PCFRS, AS, etc.)
- RF analysis.
- Characterization and Measuerements Electronic Systems (curve tracer, curve analyser, sampling oscilloscopes, nanovolt generators, lock-in amplifiers, etc.)
- Hall Effect System
- Magnetic Characterization (Vibrating Sample Magnetometer)
- Magnetic Domain Imaging.
- Electrochemical C-V Profiler

## C) Optical

- VIS and IR Fourier Transform Absorption Spectrometer (FTIRS)
- High Resolution Nomarski Optical Microscope
- Ellipsometry System
- Raman Spectroscopy
- Cryogenic Systems (5 systems)
- UV, VIS and IR Luminescence (PL) (4 systems)

## D) Devices

- Probe Stations (Low Capacitance) for VLSI and discrete devices (2 systems)
- Optical Characterization of Lasers with Spectrum Analyser
- Electrical Characterization Systems for Transistors and Devices up to 1 GHz (C-V, I-V, C-f, 1/f noise, T, etc.)
- Image Capture and Analysis System
- Optical characterization for detectors

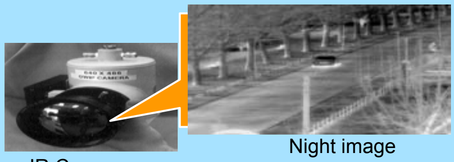
# 5. RESEARCH LINES

## Optoelectronic Sensors

**GaAs/AlGaAs/InGaAs QWIPs detectors**

Sensors Arrays

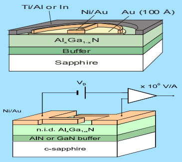
IR bi-color detection
Night vision cameras
Fire remote detection



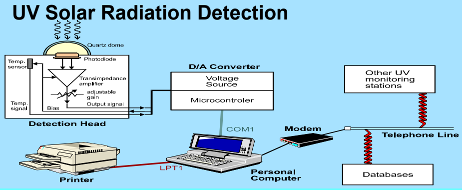
IR Camera

Night image

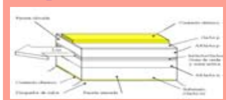
**Ultra Violet detectors based on GaN / AlGaN**




**UV Solar Radiation Detection**




## Optical Communications



**IR Diode Lasers**

- InGaAs / AlGaAs (1.1 μm)
- InGaAsN / AlGaAs (1.5 μm)

Exterior Appearence of IR Diode Laser

Optic Fiber for Communication in the IR range

**Blue and UV Diode Lasers**

InGaN / AlGaN / GaN
High density storage
High quality laser printing
Wider wideband for Optic Fibres

CD-ROM DVD

Higher density with blue-UV

**Visible and UV LED Diodes**

Information Panels
Imaging LED Screens
White light systems with high efficiency

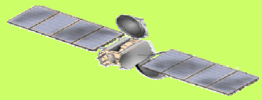
LEDS Displays

## High Speed Electronics

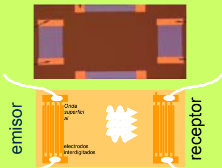
**AlGaN / GaN HEMT Transistors**

HEMT Transistor

High Power and Frequency Amplifiers
Operation at High Temperature

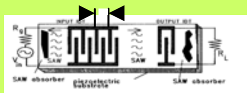


**Acoustic Surface Wave (SAW) devices based on nitrides**

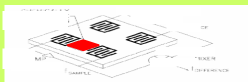



Piezoelectric substrate

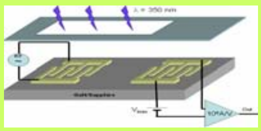
Filters for cellular phones



Chemical Sensors

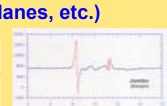


SAW Filters controled by light

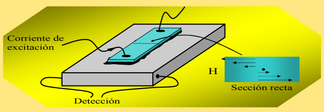


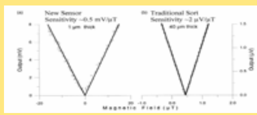
## Magnetic Sensors

Sensors for vehicle detection (automobiles, planes, etc.)

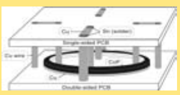


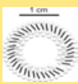
**Piezoelectric-Magnetostrictive Hybrid Sensors**

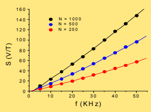


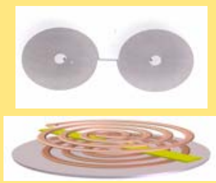
Integrated Sensors (PCB) with electrolythic magnetic core







Planar Inductors



Level and Density Sensors for Big Batteries

**Optical Sensors Systems**

- UV photo-detection systems

  - UV-B solar radiation monitoring systems
  - Contaminants and ozone detection systems based on LED's laser diodes and UV detectors.
  - Fire detection systems from UV emissions; integration with high temperature electronic components. Combustion control by flame spectroscopy.
  - UV imaging in Astrophysics

- Infrared photo-detection systems

  - High sensitivity and multispectral response detectors. AlGaAs/InGaAs quantum well and dot (QWIP's) technology.
  - Military applications. Multispectral integration. Associated electronics.
  - Environmental related IR detection.

**Systems with Magnetic Sensors**

- Magnetometric sensors for low magnetic field measurements: fluxgates, piezoelectric-magnetostrictive, magnetoresistive and magnetooptic sensors.
- Multisensors.
  - Vehicle detection applications
  - Ground airplane control and guiding
  - Applications to monitoring large battery complexes.
- Planar devices. Applications to planar inductors for commuting sources and antenas.
- Low frequency intelligent cards with magnetic sensors.

**Magnetic Microsystems**

- Magnetic multilayer structures. Application to sensor production and spintronics.
- Layered systems for magnetic anisotropy induction. Application to material design "ad-hoc"
- Nanodots and magnetic MEMS. Application to sensors and magnetic recording.

**Components and sub-systems for Optical Communications**

- Medium-power lasers from 0.9 to 1.3 µm (InGaAs/GaAs) and 1.3 to 1.55 µm (InGaAsN). Applications to optical amplification, pumping and communications with optical fibres.
- High-speed and high-contrast modulators. Devices grown on substrates with non-conventional orientations (GaAs, InP-111)
- Resonant cavity emitters (LED, 510-570 nm) for transmisión through plastic optical fibres (POF)

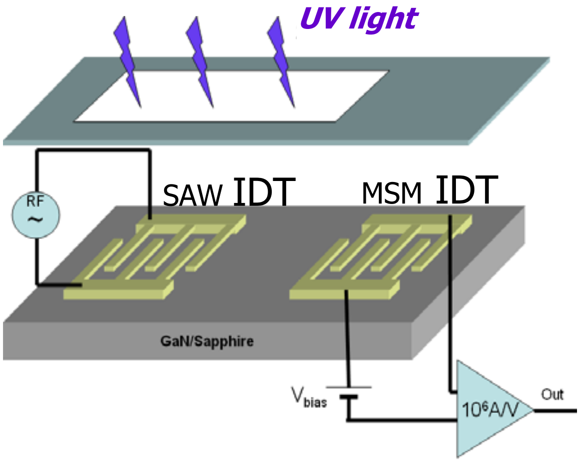
**Electronic Components for Communications**

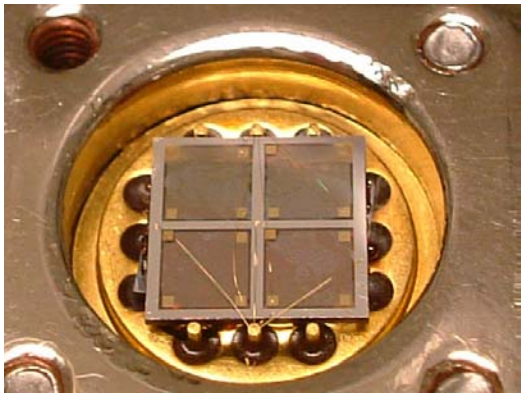
- Group III Nitride-based HEMT's(AlGaN/GaN). Applications to microwave (X-Band and L-Band). Development of manufacturing technology. Noise characteristics. Carrier transport properties. Piezoelectric effects.
- Low Noise Amplifiers (LNA)
- Acoustic surface wave (SAW) filters for RF (< 3 GHz) based on AlGaN.

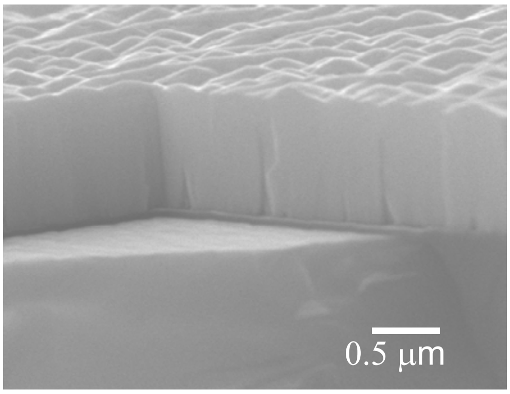
**Microsystems and Nanotechnology**

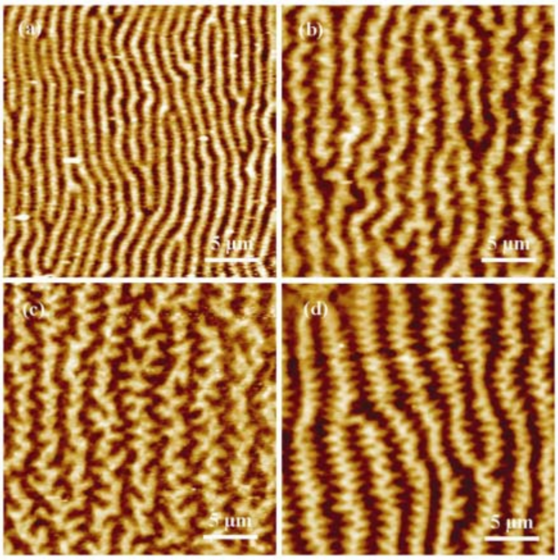
- Opto- and Electro-mechanical systems, MEMS and MOEMS. Optical detection modulation with piezoelectric devices.
- Physical, chemical and biological sensors (optical, piezoelectric, electrochemical). Polymer deposition.
- Nanoparticles, nanostructures and nanodevices.
- Atomic Force Microscope and Electron Beam Lithography.

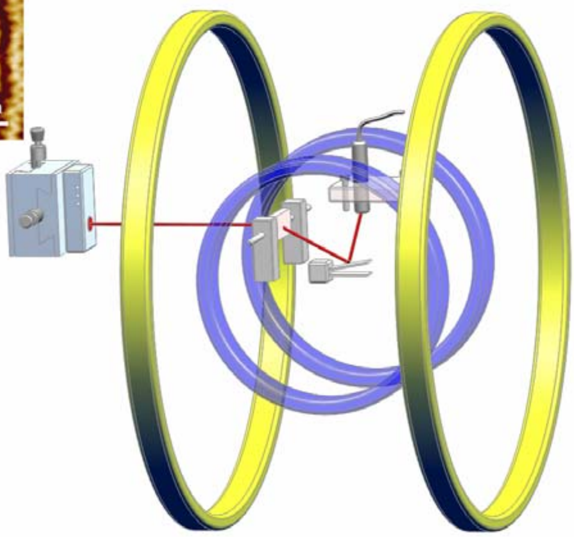
# 6. RESEARCH REPORTS

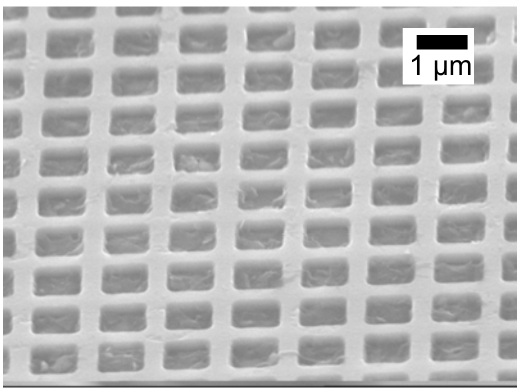






## 6.1 *Nitride-based photodetectors: from visible to X-ray monitoring*

**INTRODUCTION**

Thanks to their direct bandgap energy, $Al_xGa_{1-x}N$ photodetectors have demonstrated in the last decade visible and solar-radiation rejection ratios higher than four orders of magnitude as well as high detectivities ($D^* = 6.3 \times 10^{13}$ cm $Hz^{1/2}$ $W^{-1}$), which have made them to be very adequate for near- and mid-UV applications [1][2]. Nowadays, their intended development in fields such as biomedicine, astronomy, photolithography, or combustion monitoring requires that the operation range broadens, covering visible, vacuum-UV (VUV), and soft X-rays. Silicon-based photodetectors are currently used to work in those ranges of the electromagnetic spectrum. However, they present some problems that jeopardize their durability and reliability. X-ray photodetection requires cooling down the devices to reduce the impact of the thermally generated charge. This solution drives in many cases to the gradual degradation of the detector performance due to the cold trapping of contaminants. Additionally, exposure to high-energy radiation tends to damage the electronic properties of narrow-bandgap materials, reducing the sensitivity of the devices. On the other hand, dark currents below 10 pA at –100 V have been obtained at room temperature in Schottky barrier contacts fabricated on GaN, and high-energy radiation damage has been found to be less significant in nitrides than in silicon or GaAs [3][4].

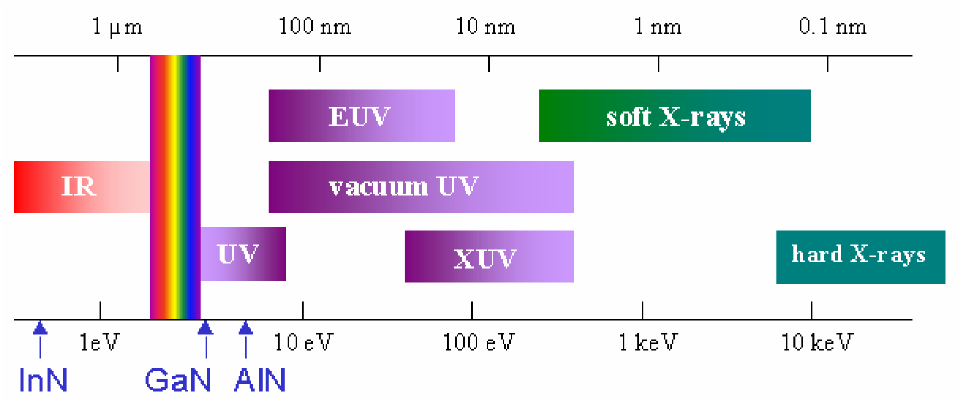



***Figure 1.*** *Electromagnetic spectrum range between IR and X-rays.*

In the visible, filters are needed to reach narrow-band detection aiming to monitor specific emissions in, for instance, bio-molecule spectroscopy or combustion monitoring. These filters are expensive, degrade with time, and decrease the detectivity of the devices. Besides, the integration of detectors and emitters becomes difficult since both are based on different technologies. To shift the cut-off wavelength of the nitride photodetectors to the visible, the growth of InGaN-based structures is needed. However, this material usually yields smooth absorption edges as a result of the In content fluctuations in the epitaxial layers. Multiple quantum well (MQW) based devices provide an interesting mechanism to overcome this drawback. Since the escape probability raises exponentially as the energy of the photons increases, the rejection ratio between the signal in the detection band and the signal in the undesired band could be enhanced. In addition, the effect of the polarization fields contributes to increase photocurrent through the spatial separation of electrons and holes, generating long lifetimes, which tends to compensate the efficiency loss produced by the barrier height in the escape from the well.

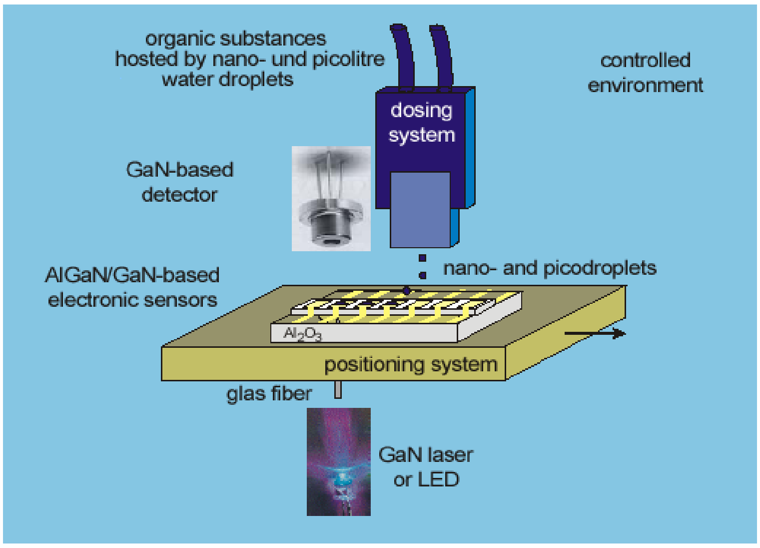



***Figure 2.*** *Integrating nitride-based photodetectors with violet and UV laser and light-emitting diodes created a compact module for use in a lab-on-a-chip [5].*

**VACUUM-UV DETECTION**

Metal-semiconductor-metal (MSM) and Schottky barrier photodiodes (SPD) have been characterised in the vacuum-UV range, making use of the Physikalisch-Technische Bundesanstalt (PTB) facilities at the BESSY II electron storage ring (Berlin). Devices were fabricated on ultra-low-dislocation density (ULD) GaN layers grown by Metal-Organic Vapor Phase Epitaxy (MOVPE). The reduction of the dislocation density is based on the maskless amorphous SiN deposition at the sapphire/GaN interface followed by further GaN lateral overgrowth in a process called micro-ELO [6].

Figure 3a shows the spectral response of GaN MSM photodiodes between 470 and 80 nm. Photodetectors showed a maximum responsivity of 40 mA/W at a 5 V bias at the bandgap edge, which corresponds to a photon conversion efficiency of 14 %. For higher energy photons quantum efficiency drops, reaching a value of 7 % at about 125 nm. Surface losses (oxide light absorption and recombination losses) are more important above the bandgap energy, as the absorption coefficient ($\alpha$) becomes higher due to the increase of the density of states in conduction and valence bands, and both can potentially provoke this response decrement [7].

For shorter wavelengths ($\lambda$ < 120 nm), the measured photoresponse keeps steadily constant and even increases with photon energy. Two phenomena are responsible for this behavior. First, in that range, the absorption coefficient begins to decrease with photon energy, so the carriers are optically generated deeper in the epitaxial layer, and the surface recombination become less significant. On the other hand, photon energy may now correspond to, and be above, the ionization energy of GaN, which means that the number of electron-hole pairs created by each impinging photon should begin to raise in average for energies above it. The theoretical estimation of this ionization energy parameter gives a value between 10.0 eV and 10.5 eV, in good agreement with the energy value (10.3 eV) from which the response enhances [8].

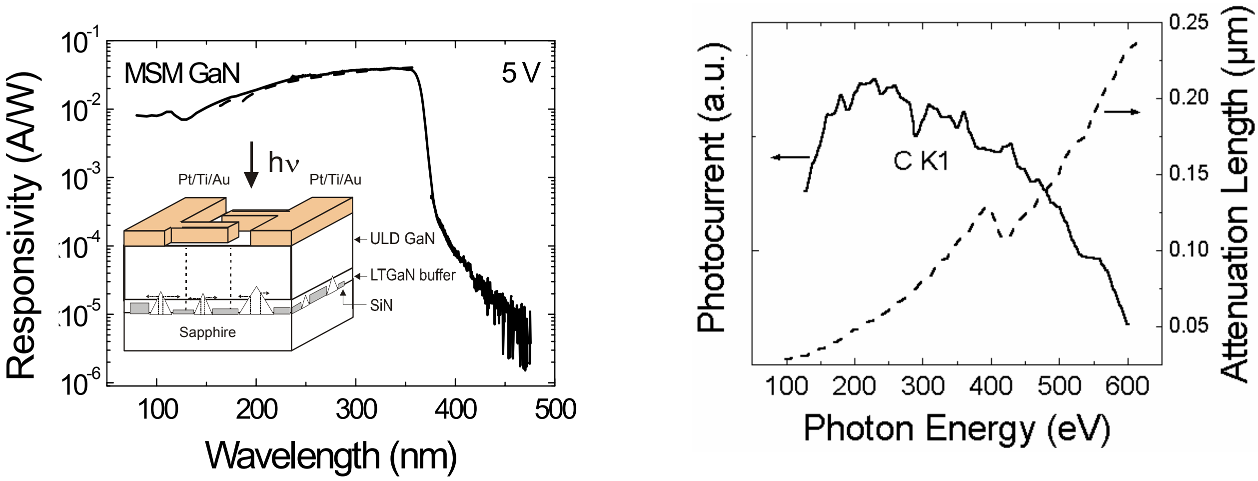



***Figure 3.*** *a) Spectral response of MSM photodiodes in the 80 nm to 360 nm range at a 5 V bias (solid line). The dashed line represents the fitting of the experimental data between 155 nm and 360 nm following the dead layer model. The inset shows a scheme of the process route for the epitaxial growth of ULD-GaN layers. b) Photocurrent measurements performed on* $Al_xGa_{1-x}N$ *(x = 0.02) MSM photodiodes between 100 and 600 eV (left axis). The right axis represents the attenuation lengths calculated at those energies.*

## SOFT X-RAY DETECTION

X-ray characterization was performed by using $Al_xGa_{1-x}N$ (x = 0.02) MSM photodetectors grown on silicon by Plasma-Assisted Molecular Beam Epitaxy. The device photoresponse between 100 and 600 eV is shown in Figure 3b. Up to our knowledge, this is the highest photon energy ever used to measure nitride-based MSM detectors. Many of the optical elements in synchrotron beamlines are based on SiC, provoking a depression of the radiation intensity around 290 nm, the K1 transition of atomic C. This feature is visible in the spectrum, demonstrating the significant sensitivity of the devices in these ranges. It is interesting to notice how the photocurrent generated by the device gradually decreases above 200 eV. This is consequence of the increasing attenuation length (L) when the photon energy raises. The right axis represents the value of this parameter in the same spectral range, as calculated from the atomic scattering factor [9]. The one-dimensional simulation of the structure showed that the L values begin to be comparable to the space-charge-region width (210 nm), the diffusion length becoming a crucial parameter for the collection of the generated carriers. This parameter is rarely larger than a few microns in nitrides, so the signal collapses when the light absorption decreases. Even in the case that those values were enough high to allow charge collection, the response would be limited by the thickness of the AlGaN epitaxial layers. Thus, thick AlGaN layers are desirable to detect X-rays. The enhancement of the depletion region by the fabrication of p-i-n or Schottky photodiodes on highly resistive material would drive to a better performance in those ranges, as in Si or GaAs technologies.

## InGaN/GaN MQW-BASED PHOTODETECTORS

Prototypes based on large area (3 x 3 mm$^2$) p-i-n photodiodes have been fabricated to detect near-UV and visible emissions in field measurements. The active region consists of 3 or 6-period InGaN/GaN quantum wells, typically with well and barrier thicknesses of 3 and 15 nm, respectively. A 20 nm thick p-$Al_{0.2}Ga_{0.8}N$ barrier was grown on the top of the active region, just below the GaN p-layer. Responsivity is peaked at about 360nm, due to the bulk GaN p-type region, providing responsivities around 100 mA/W, typically, decreasing at shorter wavelengths (Figure 4b). It was also found that responsivity increases as In content grows, which seems to be caused by the presence of higher polarization fields in the quantum wells. Although these polarization fields reduce wavefunction overlapping, escape probability is enhanced.

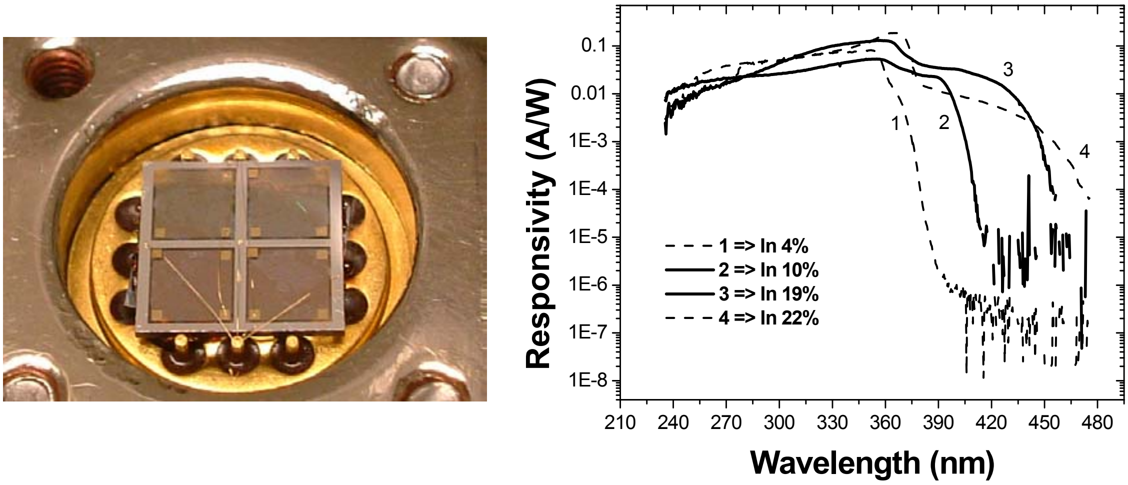



***Figure 4.*** *a) Prototype of a InGaN/GaN multiple-quantum-well detector with an active area of 6 x 6 mm$^2$. b) Spectral response of different InGaN/GaN MQW p-n junctions. Dashed lines belong to 3-period MQW photodiodes while solid lines to 6-period MQW photodiodes.*

As it is well known, strong piezoelectric effects are present in nitride devices, causing a significant influence in device performance, and usually observed through the quantum-confinement Stark effect (QCSE) and oscillator strength determinations in optical transitions [10]. In the case of a Schottky barrier with MQW in the active region, the effect of piezoelectric fields becomes even more important than in p-i-n diodes, where the built-in voltage is threefold.

For a given InGaN/GaN system, by properly selecting well and barrier thicknesses, the average electric field in the period may be either positive or negative [11]. Figure 5 shows that, as a function of device bias voltage, three modes of operation can be generated. The average electric field in the 5 period MQW region can have the same sign that in the tail of the diode depletion region, or can be practically zero, or to have an opposite sign, generating a field that points towards the ohmic contact. Under this last operation regime, potential minima are generated at the extremes of this MQW region, and charge accumulation will take place. The transition from one regime to the other one appears at a forward voltage of around 0.5V (zero average field or ZAF). Reverse voltage bias is high enough to compensate the piezoelectric raising effect of the band bending, and the detector behaviour is similar to a standard Schottky photodiode.

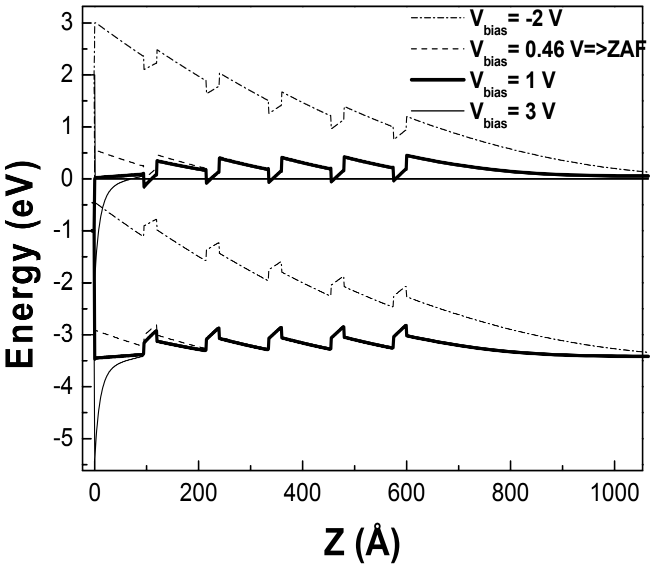



***Figure 5.*** *Band diagram of the Schottky barrier photodiode with quantum wells embedded in the active region at different voltage biases.*

By increasing the voltage bias, $V_{bias}>V_a$, a potential minimum for holes is created in the middle of the space charge region, in the first well, and also a local potential minimum for electrons is present in the last well, just below the metal barrier. In this situation, under illumination with photons above InGaN bandgap, electrons and holes in the depletion region will tend to drop into the lowest potentials, with holes tending to remain trapped in the first well while electrons will be confined in the last one. In any case, carriers can be also trapped in other quantum wells, not being able to reach potential minima. Since electrons can escape more easily than holes, the depletion region remains positively charged, increasing the capacitance of the device. If the voltage bias applied is even higher, quantum wells close to the surface can become occupied and accumulation in the contact is produced.

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## 6.2 *Quantum well infrared photodetectors (QWIP)*

**N-DILUTE BASED QWIPS FOR IR ABSORPTION BELOW 4 µm.**

During the last years, the Institute for Systems based on Optoelectronics and Microtechnology (ISOM) has a very active research line focused on the growth and characterization of infrared quantum intersubband detectors with operation wavelength in the atmospheric transmission window at 3-5 µm. Among the different structures employed to fabricate these devices, the so-called "bound to quasi-continuum" one is the only suitable to reach the wavelengths of interest. In this case, a GaAs quantum well is sandwitched between two thin AlAs inner barriers (20 Å wide) and further separated by a AlGaAs barrier 300 Å wide as shown in fig. 1. The transitions take place from a ground level bound in the quantum well to a second level partially confined by the AlAs barriers. The electrons promoted to this latter, escape tunneling the thin barrier giving rise to a net photocurrent at the contacts. To ensure the presence of carriers in the ground level, it is necessary to introduce n-type doping species near the quantum well. Most of the published works report on doping the quantum well, however, one of the original contributions of the Institute is the use of modulation doping techniques to improve the performance of the devices (photovoltaic behaviour and peak linewidth reduction) [1][2].

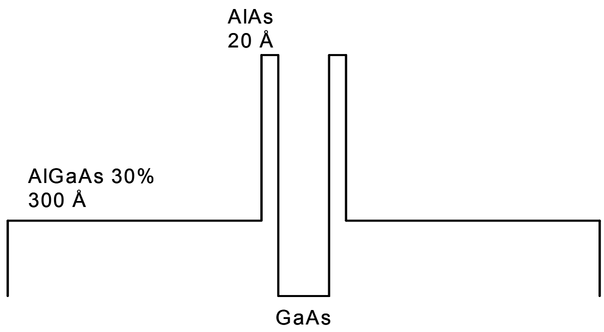


***Figure 1.*** *Conduction band profile of a QWIP with operation wavelength in the 3-5 µm window*

Despite the obvious advantages of this material system (maturity, low cost, high yield, homogeneity and reproducibility), many groups are still reluctant to use it for array development at 3-5 µm. This is partially due to the fact that the absorption wavelength is highly dependent on the quantum well width, specially in the case of very thin QW (less than 50 Å), where a deviation of around 5 Å in the well width leads to a displacement of ~0.8 µm in the absorption peak. It is also due to the strong increment in the dark current observed when the thickness of the GaAs quantum well is reduced below 45 Å. In this case, the ground level is pushed to the top of the AlGaAs barrier becoming resonant with it, thus giving a high tunnel current even in the absence of incident light. Because of all of this, the practical application of these detectors to the wavelength range between 4 and 5 µm is limited.

One of the most important original contributions of the Institute is the use of N-dilute alloys (InGaAsN and GaAsN) to extend the operation of the devices below the limit at 4 µm. The introduction of a small molar fraction of N in the GaAs crystal lattice leads to a strong reduction in the bandgap, therefore, in theory it is possible to tailor the detector to work below 4 µm avoiding the increment in the dark current.

A large number of samples were grown by Molecular Beam Epitaxy in collaboration with the University of Sheffield (Sheffield, UK). These samples were further processed into photodetectors and characterized in the ISOM. First, we performed a detailed study of the properties of the N-dilute based QWIPs using simulation tools developed in the Institute. The theoretical models employed, were based on the so-called band anti-crossing (BAC) method which predicts a high effective mass for the material used in the QW (GaAsN) very similar to the effective mass of the AlAs barriers. This leads to the existence of more than two energy levels in the well, and hence, more than one intersubband transition may be possible, as observed in the experiments (fig. 2).

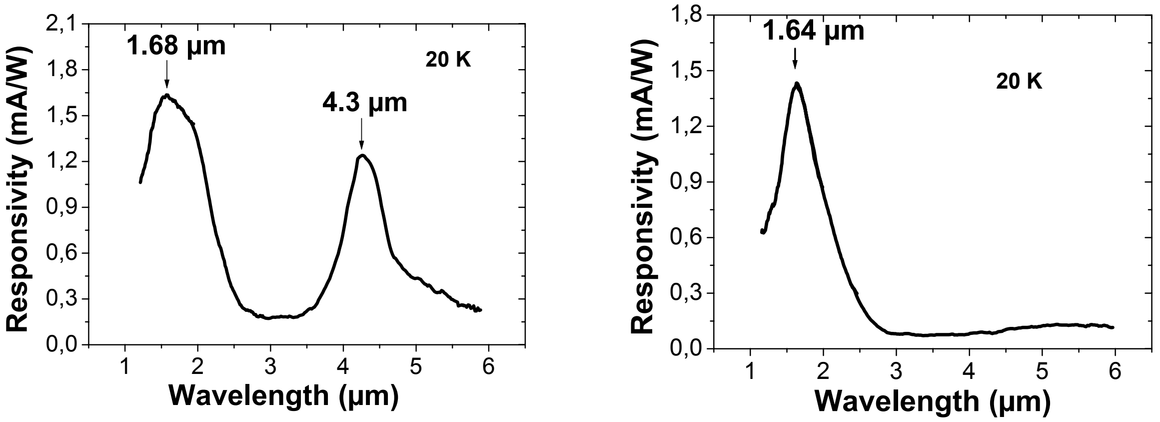


***Figure 2.*** *Responsivity of dilute N based QWIPS. The large effective mass of this material (comparable to AlAs) allows to accommodate more than two levels in the quantum well (left) leading to different transitions in the IR range. On the right, it is shown the Responsivity of a QWIP with only two levels.*

However, some samples were designed and grown to accommodate only a ground level and a partially confined one as in the case of GaAs based detectors. These samples consist of a very thin (25 Å) GaAsN quantum well sandwitched between two AlAs barriers. In order to improve the growth of the GaAsN layer, two monolayers of GaAs were introduced at both sides of the quantum well. The large bandgap discontinuity between the material of the QW and the AlAs ensures a low dark current as well as the existence of a single absorption peak below 4 µm. Figure 2, shows the responsivity spectrum for this sample, where a single photocurrent peak below 4 µm is observed as expected. To our knowledge, this is the first observation of intersubband transitions in N-diluted based QW in the range of 3-5 µm [3][4].

## FABRICATION OF GaAs BASED QWIP ARRAYS FOR FOCAL PLANE CAMERAS

One of the main applications of the quantum well infrared detectors is the development of focal plane arrays to be used as the active elements in the fabrication of IR cameras. The homogeneity and reproducibility of the GaAs/AlGaAs material system makes it very suitable for this purpose and hence, many references from different groups around the world (Jet Propulsion Laboratory (JPL) NASA, Air Force Research Lab., Northwestern University Chicago, Fraunhoffer Institut Freiburg, etc.) can be found concerning the development of such devices. They are usually grown using Molecular Beam Epitaxy (MBE) or Metal Organic Chemical Vapor Deposition (MOCVD) techniques, therefore, in principle it is also possible to stack several structures in a detector to achieve multispectral response.

However, because of the quantum selection rules affecting the intersubband transitions, the major drawback of these arrays is the absence of photosignal when the electric field of the incident light has components parallel to the growth surface. This limitation is usually overtaken by the definition of a diffraction grating on top of the detectors which scatters the light giving rise to an improvement in the absorption process. The optimum dimmension and periodicity of the diffraction grating was proven to be strongly dependent on the operating wavelength of the detector involved.

Up to now, most of the QWIP array cameras reported are designed to operate in the 8-12 µm atmospheric transmission window. This IR interval is easily covered using AlGaAs/GaAs quantum well structures and diffraction gratings defined by standard photolithography (periodicity ~3 µm). It is also possible to find a few references about QWIP cameras working in the 3-5 µm window, where the definition of the diffraction grating involves the use of electron beam lithography systems (periodicity below 1µm). Some dual wavelength cameras (4 and 10 µm) have been also reported by JPL.

The Institute is currently collaborating with other research centers and companies in an important national project aimed to the development of a three-color focal plane array camera to be used as a night vision system in the mid-infrared range (3-5 µm). The detectors are grown by MBE in the Institute, on GaAs (100) substrates. They consist of three different active regions separated by thick (1 µm) GaAs n-doped contacts. These active regions are tuned to absorb light at 3.8, 4.2 and 4.6 µm respectively. After the growth process, three different diffraction gratings depending on the operating wavelength are defined on top of the detectors using electron beam nanolithography and Reactive Ion Etching (RIE). The samples are then processed into photodetectors by standard photolithography and RIE with an ohmic AuGe contact on top of the devices. The different active regions are selected by means of a metal stripe that shortcircuits the regions not used thus leaving a direct electric access to the region of interest. Figure 3 summarizes the characteristics of the detectors as well as the processing technique.

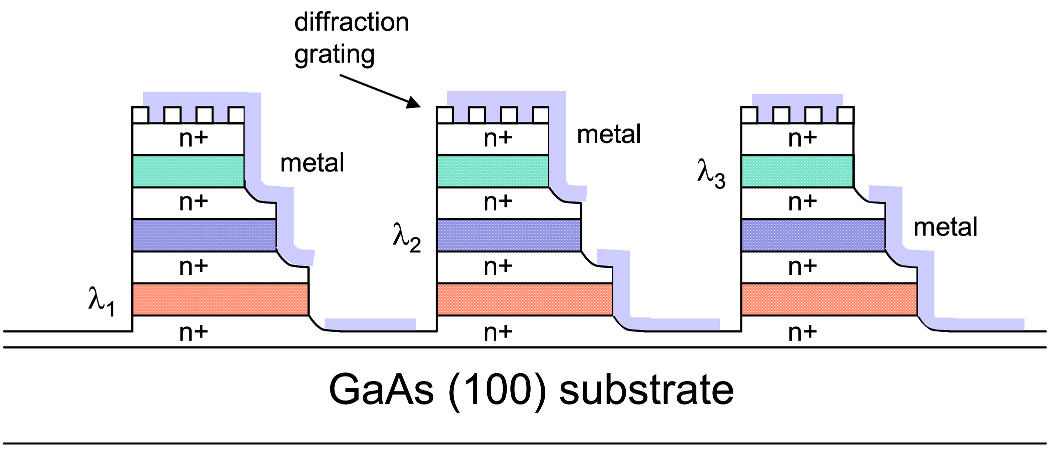


***Figure 3.*** *Structure and processing of three-color detector arrays. The active regions are separated by n+ GaAs contacts and the metal stripes select the active detector in each case.*

The main interest of the ISOM in this field is the search for an optimized diffraction grating that maximizes the photosignal in each wavelength of interest. Several designs were tested including circle, stripe and square shaped gratings as well as different periodicities and etching depths. In all cases, it has been obtained a very good degree of reproducibility both in the growth and in the processing techniques. The diffraction gratings always show well defined edges and homogeneity for submicronic dimmensions as low as 400 nm. The devices were assessed by photocurrent and responsivity measurements using a IR glowbar as the light source, a monochromator and ZnSe optics. Figure 4 shows the final aspect and the efficiency of the diffraction grating (calculated as the quotient between the photosignals of a detector with and without grating) for different shapes and periods. We have found that this parameter is highly dependent on the ratio between the etched and non etched area, which makes necessary a high degree of accuracy in the nanolithography and etching processes.

The conclusions of these studies were employed for the development of three color detector arrays. The preliminary results obtained are very promising for a future hybridation of these arrays with a Si based read out electronics and its further application in night vision cameras.

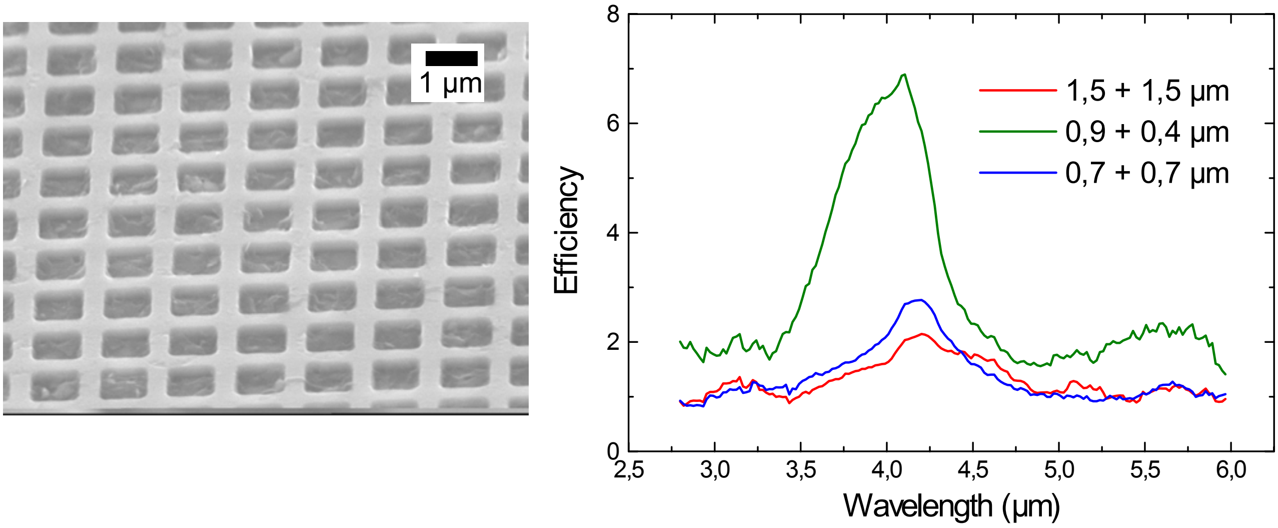


***Figure 4.*** *Final aspect and efficiency of different diffraction gratings defined on top of IR detectors. The values of efficiency are calculated as the ratio between the response of a detector with and without grating. The dimmensions in microns correspond to the size of the pattern and the periodicity of the grating.*

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# 6.3 Diluted Nitrides for IR Applications

The quaternary alloy GaInNAs has attracted much attention in recent times due to its potential application for optoelectronic communications at 1.3 and 1.55 µm.[1] At ISOM, a large effort is being devoted to this new material, covering all areas from the growth by MBE, to the characterization of the material properties, modelling and design of structures and devices, and processing and characterization of devices such as LEDs, LDs and QWIPs (see report on QWIPs for more details). The results in all these areas are summarized below.

**MBE GROWTH OF GaInNAs/GaAs QWS**

P-i-n devices on different (100) and misoriented (111)B susbtrates have been fabricated by MBE. It was found that a higher As flux is required to achieve similar crystal quality for the growth of GaInNAs quantum wells compared to InGaAs QWs. GaInNAs QWs grown on substrates misorented towards [2-1-1] showed a higher integrated PL intensity than substrates misoriented towards [-211] (Fig. 1). The Optical Emission Detector (OED) intensity has been found to be a good control parameter for the nitrogen incorporation in GaInNAs layers.[2] It was also observed that the crystal quality of (111)B samples improves significantly after post-growth RTA, like it is the case for (100) (also see next section). Up to around 3% nitrogen has been incorporated to the quantum wells in both (100) and (111) GaAs substrates.[2,3]

A high dependence of the nitrogen incorporation on growth temperature was also found (Fig. 1). Even the unintentional temperature gradient in the substrate holder causes strong shifts in PL emission wavelengths. An expression relating PL peak emission wavelength and growth temperature was derived using thermodynamic considerations and PL observations.[3] The growth temperature is therefore a key parameter in the growth of diluted nitrides on (100) and (111)B GaAs to achieve good optical quality, due to the strong dependence of the N content and integrated intensity and FWHM of the samples. Wavelengths as long as 1.42 µm at low temperature have been obtained, in the case of (111)B, the longest reported up to date.[2-4]

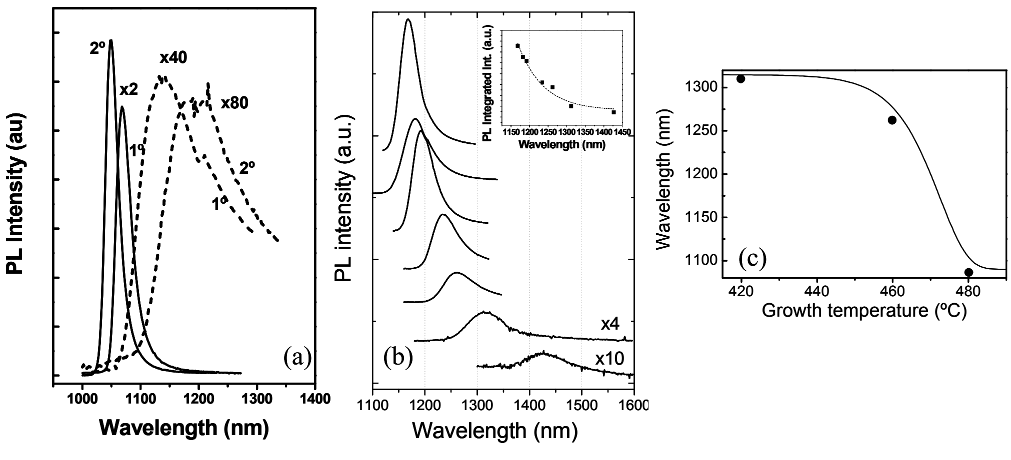


***Figure 1.*** *(a) PL measurements at 11K of two GaInNAs p-i-n diodes. Dotted lines represent as-grown samples. Solid lines represent the same diodes after anneal (b) Different low temperature (16K) PL measurements of the same sample (70 Å InGaAsN QW, 26%In, (111)B taken in different positions of the wafer. Spectra are vertically shifted for clarity. The inset shows the integrated intensity for the different positions (black squares). The dotted line is a exponential fitting for the data. (c) Low temperature PL peak position versus growth temperature. The solid line represents the empirical expression, and the solid circles represent the data from three different samples.*

## MICROSTRUCTURE AND OPTICAL EMISSION OF GaInNAs/GaAs QWS

The impact of annealing on the optical emission of GaInNAs QWs has been shown to be highly dependent on the microstructure observed by TEM, and to correlate to the growth regime. The QW that shows a very rough upper interface, at the onset of 2D to 3D growth, requires the highest anneal temperature in order to achieve luminescence emission, but cannot reach high temperature PL emission (Fig. 2). In contrast, the QWs with sharp interfaces require lower anneal temperatures and are able to produce luminescence at high temperature. In particular, the presence of small compositional variations in the QW lead to higher anneal temperatures in order to obtain light emission. Thus, the generation of non-radiative recombination centers is likely enhanced not only by 3D growth but also by the appearance of compositional fluctuations along the QW.[5]

Both the presence of carrier localization centers and the role of annealing strongly correlate to the microstructure of the QW. Two important conclusions can be drawn. First, the localization states extend deeper into the bandgap for QWs with strong compositional fluctuations, and is closer to the conduction band edge for smooth 2D QWs. Second, when large compositional fluctuations are present in GaInNAs, annealing has a large impact on this band of states, which becomes narrower and closer to the conduction band edge. However, this effect is weaker in the smooth 2D QW, consistent with the fact that as-grown this same sample has fewer localization minima below the conduction band.[5]

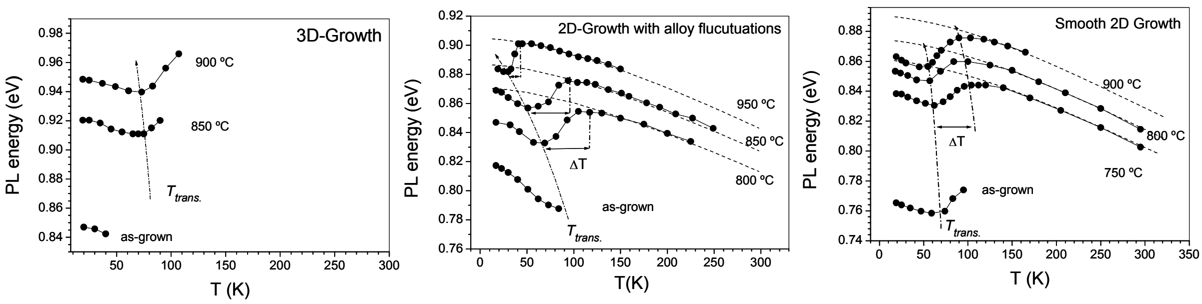


***Figure 2.*** *Temperature dependence of the PL peak energy for the different GaInNAs QWs as a function of annealing. The dashed lines correspond to the bandgap energy for the same QWs calculated using the BAC model.[6] ΔT defines the temperature regime where there is a transition from localized to band edge emission, and the onset to this regime is defined as* $T_{trans}$.

## ELECTROLUMINESCENCE FROM GaInNAs/GaAs LEDs

A detailed study of the EL of GaInNAs/GaAs QW LEDs shows that the localized states dominate the emission only at low temperatures and currents, due to the small localization energy and density of states. A small increase in temperature or current leads to an emission dominated by conduction-band to valence-band transitions, which are less efficient. The non-radiative recombination increases strongly with temperature, and becomes the dominant mechanism above 150 K.[7] Non-radiative recombination also reduces strongly the η(ext) and is the main factor limiting light emission at RT. RTA is shown to improve the optical properties of the device, increasing the η(ext) by an order of magnitude. This is likely due to a reduction of non-radiative recombination centers after annealing, as evidenced by the reduction in the monomolecular recombination saturation current.[7]

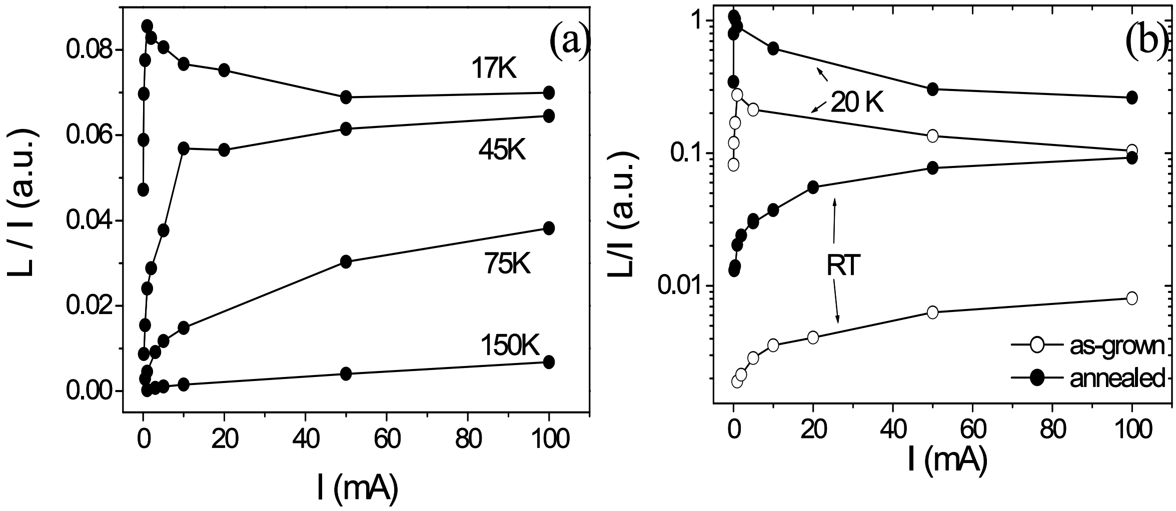


***Figure 3***. *Ratio of integrated light intensity to injected current (i.e., external quantum efficiency) as a function of injected current for a GaInNAs LED at different temperatures (a), and as a function of annealing (b).*

**EDGE-EMITTING GaInNAs LDs.**

Several broad area LD structures have been fully designed using the BAC model,[6] grown by MBE, processed and characterized at ISOM, both on GaAs(111) and (100). On the latter, preliminary analysis already shows very encouraging results with laser emissions at wavelengths up to 1.27 µm at 230K for In and N concentrations of 30 and 2%, respectively (Fig. 4). In agreement with the results for the LEDs, the lasing threshold current density is highly dependent on T, preventing lasing emission at high T due to the large concentration of active non-radiative recombination centres. Further analysis and development of these structures is currently being performed.

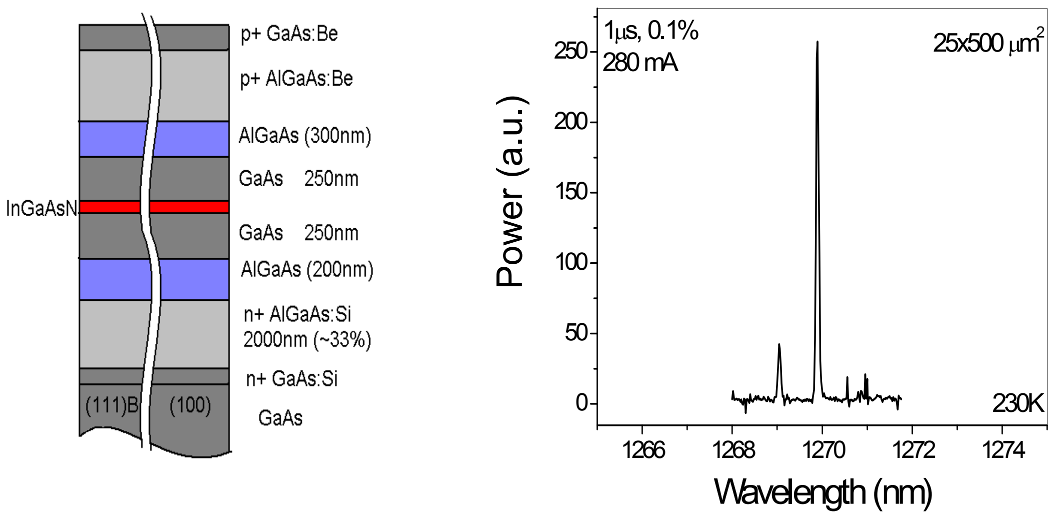


***Figure 4***. *LD structure and lasing emission from a broad area SQW GaInNAs/GaAs LD on (100)GaAs.*

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# 6.4 Nitride-based SAW Devices: Properties and Novel Applications

**Abstract** — *Some properties and applications of surface acoustic wave (SAW) devices based on III-V nitride films (AlN, GaN) are studied. The excellent characteristics of these materials for high frequency applications are demonstrated by the fabrication of SAW filters with central frequencies higher than 2.2 GHz. The thermal behavior of these filters has been analyzed. Together with the Rayleigh modes, some other modes have been observed, both of guided (Sezawa) and bulk (pseudo-Sezawa) character. The anisotropy of the SAW modes in devices grown on sapphire has been studied. Besides the conventional applications of SAW devices for MW filters and gas sensors, some others are discussed as a result of the integration of SAW devices with metal-semiconductor-metal photodetectors and 2-DEG AlGaN/GaN structures.*

## INTRODUCTION

Surface acoustic waves (SAW) devices are the most convenient solution for high frequency filters in communication systems due to their stability, reliability and compactness [1]. In addition, SAW filters are ideal for gas sensing [2,3], as their operation is modified by the ambient conditions, with many industrial, environmental and medical applications. Furthermore, SAW sensors offer the additional feature of wireless transmission [4,5], and therefore the feasibility of operation in harsh environments.

A SAW device consists of a piezoelectric film on which two interdigitated transducers (IDT) are deposited, so that high frequency ac electric fields can be converted in acoustic waves, and vice versa. Fig. 1.a shows the operation procedure: the input signal at the first IDT is transformed to an elastic perturbation which propagates along the film surface towards the output IDT. The elastic wave is efficiently excited at the frecuency $f=v_S/\lambda$, where $v_S$ is the SAW velocity, and $\lambda=4d$ the IDT periodicity. Thus, the device operation range is limited by the velocity and the available lithographic resolution for the electrode fabrication; e.g., using a material with $v_S$=4000 $ms^{-1}$, and d=1 μm, filters with central frequency of 1 GHz can be achieved. On the other hand, the relative bandwidth, $\Delta f/f$, is inverse to the period number in the IDTs.

SAW devices are typically fabricated on quartz and $LiNbO_3$. However, new piezoelectric materials where SAW devices can exhibit novel or improved characteristics have been identified. Among them, the III-nitride family combines a high SAW velocity and reasonable electromechanical coupling coefficients, while showing excellent thermal and chemical stability. These properties are of high interest for the development of SAW devices operating at frequencies higher than 1 GHz, a common requirement of most modern telecom applications. Moreover, the semiconductor character of AlGaN and its direct bandgap enables the integration of SAW devices with electronics and optoelectronics.

In the following sections we report on the fabrication and characterization of SAW filters on AlGaN epilayers. The performance of these devices is analyzed as a function of temperature. A critical aspect regarding sensing applications, namely, the reproducibility of the central frequency, maybe affected by the anisotropy found in devices grown on sapphire due to different crystal structures, an issue which is addressed. Finally, two novel devices based on surface acoustic waves are presented: a SAW-assisted photodetector, based in the integration of a SAW generator and an ultraviolet photodetector, and a DC controlled SAW filter, obtained by the fabrication of a SAW device on a 2-DEG AlGaN/GaN heterostructure.

## FABRICATION AND CHARACTERIZATION OF SAW DEVICES

The SAW filters presented in this work were fabricated on 0.2-15 μm thick (AlGa)N epilayers grown by molecular beam epitaxy and metalorganic chemical vapor deposition on c-sapphire. The morphological and structural quality of the samples was assessed by atomic force microscopy and high resolution x-ray diffraction. The surface acoustic velocity was measured by Brillouin spectroscopy as a function of sample orientation [6].

The filters were fabricated using either contact lithography, to pattern interdigitated electrodes with identical finger widths and pitches ranging from 16 μm to 2 μm, or an e-beam lithography system optimized for nitrides [7] to obtain IDTs with features from 2 μm to 0.5 μm (see photo in Fig. 1.b). After the lithography, a thin Ti/Al or Ni layer was deposited by e-beam or thermal evaporation. In a second lithography, the bonding pads were metallized. An HP8510C network analyzer was used to measure the transfer function of the different devices.

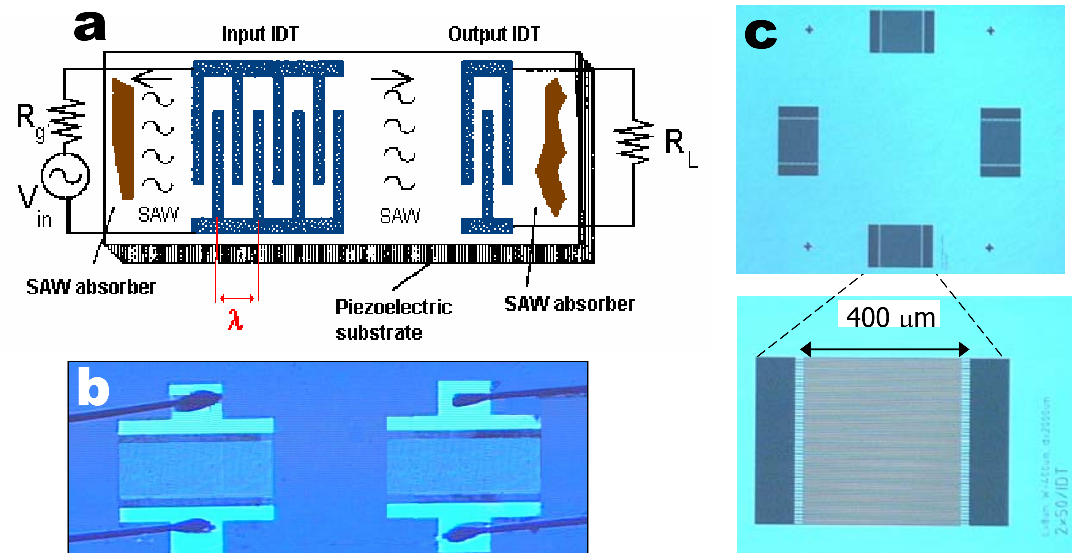



***Figure 1.-*** *a) Scheme of a SAW device; b) SAW filter on AlN fabricated by electron lithography (IDT: d=0.6 μm, N=100); c) two orthogonal SAW filters on GaN fabricated by photolithography, and detail of an IDT (L=400 μm, d=2 μm, N=50).*

In bulk material, surface waves are called Rayleigh, and their frequency is given by $f=v_S/\lambda$. However, in a film layer of thickness H, $f$ depends on the elastic properties of the substrate, since the SAW propagates with a penetration depth in the order of the acoustic wavelength λ. Additionally, guided modes (Sezawa) arise when the sound velocity in the overlayer is lower than in the substrate (slow-on-fast structure), and new leaky, pseudobulk modes may also appear at higher frequencies.

Therefore, two behaviors have been observed in filters fabricated on AlN and GaN, due to their different sound velocities (v = 5790 $m \cdot s^{-1}$ and 3693 $m \cdot s^{-1}$, respectively) respect to sapphire (5495 $m \cdot s^{-1}$) [8]. Fig. 2.a) shows the transfer function for two SAW filters on AlN, with λ=6 and 4 μm, each including the Rayleigh mode; on the other hand, the transfer function of one SAW filter in GaN (λ=2.4 μm) is shown in Fig. 2.b), where the peaks at 1.6 GHz and 2.2 GHz correspond to the Rayleigh and Sezawa waves. These results demonstrate the suitability of GaN as a reliable film for SAW filters operating at frequencies above 2 GHz. Fig. 3.a) shows the dispersion relation of several modes in GaN for the [1-100] direction of sapphire [9]. The experimental data are in full agreement with the simulations (circles).

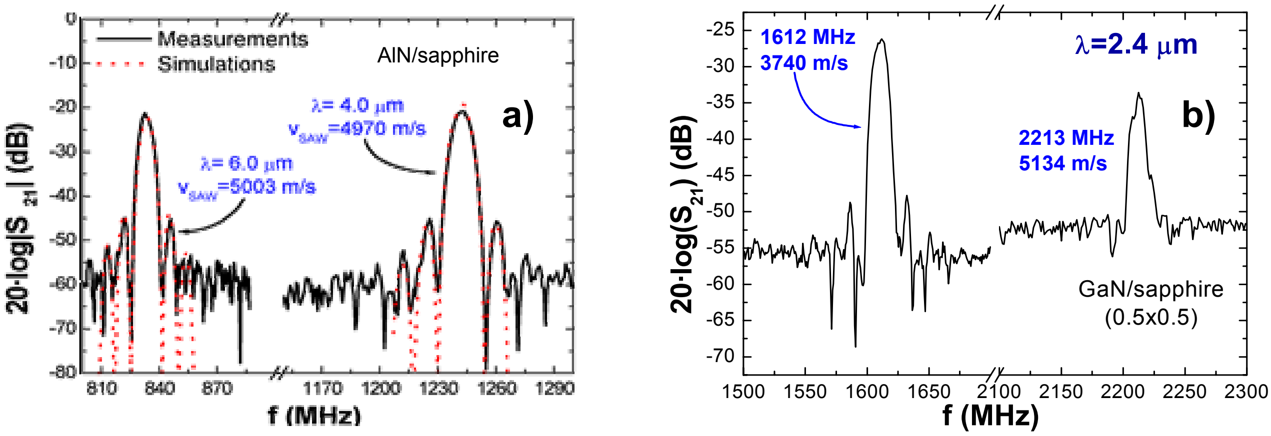



***Figure 2.*** *Transfer functions of a) 2 different SAW filters in AlN, with their respective Rayleigh modes, and b) one SAW filter in GaN, showing the Rayleigh and confined modes.*

The substrate may also lead to an anisotropic propagation of sound. In fact, the nitride films have the wurzite crystal structure, whereas the thick sapphire substrate is trigonal. This crystal mismatch induces a dependence of the SAW frequency with orientation, either for GaN and AlN [9]. Filters along orthogonal directions have been fabricated on GaN and AlN epilayers (see Fig. 1.c). The transfer functions of two SAW filters on a GaN/sapphire along the [11-20] and [1-100] directions are shown in Fig. 3.b). The substrate induced anisotropy can be observed in the modes frequencies and in the coupling efficiencies (e.g., the Sezawa peak is damped in the [1-100] orientation), while the pseudo-bulk mode is splitted in two different peaks along [11-20].

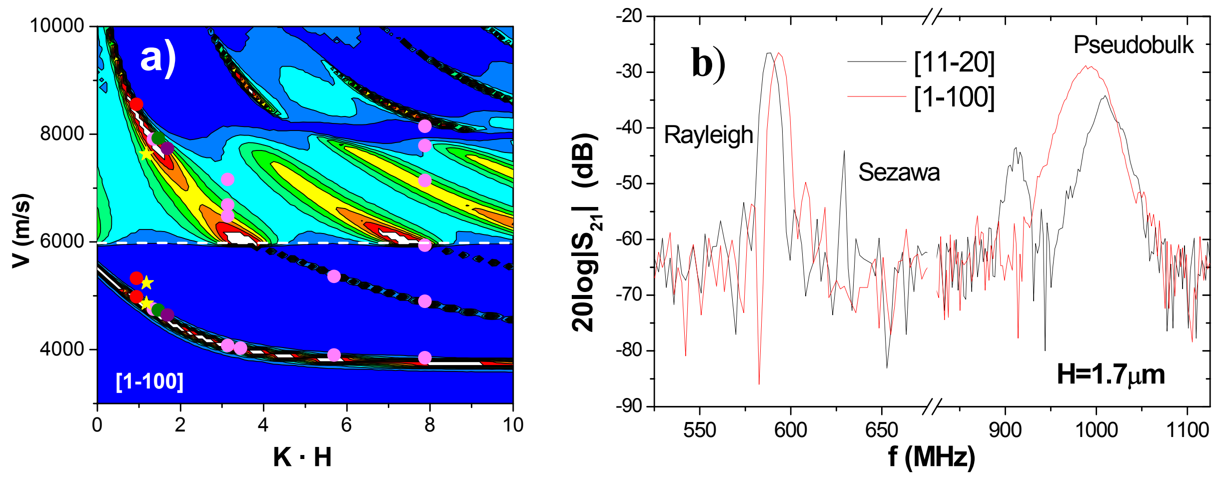



***Figure 3.*** *SAW filters on GaN/sapphire: a) Comparison of the simulated dispersion relation for the [1-100] orientation and experiment. b) Transfer functions in the [11-20] and [1-100] directions, showing the substrate induced anisotropy.*

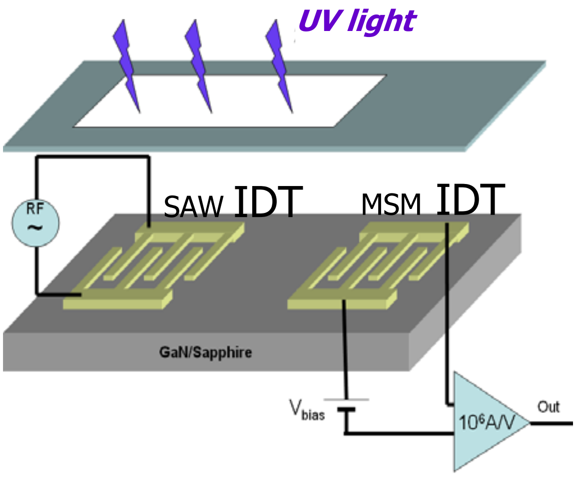
The influence of temperature in the SAW frequencies has been measured in the 50-400K range, and thermal coefficients of delay of –68 ppm·$C^{-1}$ for AlN and of –43 ppm·$C^{-1}$ for GaN were obtained. These values, higher than expected for III-nitrides, are likely due to the influence of the sapphire substrate.

## NOVEL APLICATIONS OF NITRIDE SAW DEVICES

Most nitride-based SAW devices are oriented to communications and sensors. Usually, AlN is deposited by sputtering on Si substrates. Other substrates -like diamond, which holds promise for high temperature applications- and growth techniques may provide some advantages. In particular, we will describe two novel applications as a result of the interaction of SAW with photons and electrons in crystalline material: a UV GaN photodetector assisted by SAW, and a DC controlled SAW filter fabricated on a 2DEG AlGaN-GaN heterostructure.

## INTEGRATION OF SAW WITH OPTOELECTRONICS

The interaction of SAW and photons has been also studied to evaluate the feasibility of remote sensors. The bandgap of GaN is 3.4 eV, corresponding to UV radiation (365 nm). The experimental set-up is shown in Fig. 4. Two IDTs, with 2 μm finger width and pitch distances, are deposited on a GaN/sapphire layer as described before. One of the IDTs is connected to an HP E4400 RF signal generator in order to produce a SAW traveling on the GaN surface, whereas the other is used as a metal-semiconductor-metal (MSM) photodetector. Only the inter-IDT region is illuminated. An electrometer is used to measure the photocurrent detected by the MSM photodetector. In this experiment, the frequency of the RF generator is varied to observe its influence in the detected photocurrent.



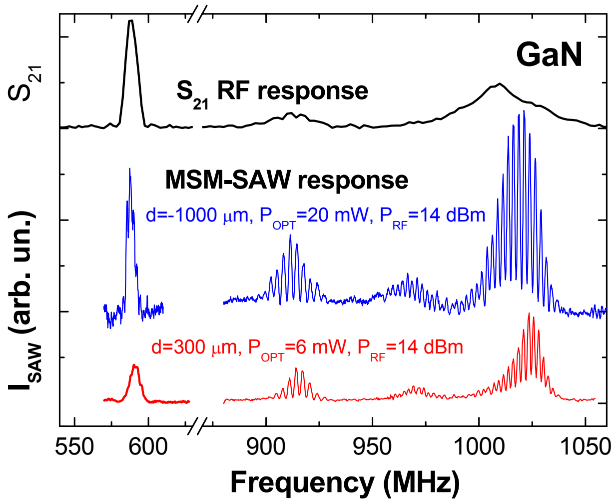




***Figure 4.*** *Experimental set-up for the integration of a SAW generator and the MSM UV photodiode (left), and comparison between the filter RF response and the spectral responsivity of the MSM-SAW detector (right).*

Without illumination of the region between the IDTs, the response due to the dark current is very low, and does not change with the RF frequency. However, under illumination, an increase in response is observed when the RF frequency injected in the SAW generator tunes its specific frequencies [10]. Figure 4 compares the transfer function of the SAW filter with the spectral responsivity of the MSM as a function of the RF frequency injected in the SAW generator. The increase of the responsivity at the SAW-filter center frequency is related to the sweep of photogenerated carriers from the place where generated to the detector IDT by the waves. Once carriers reach the MSM detector, the electric field at the depletion regions of the MSM Schottky contacts breaks the fields associated to the SAW and collects the carriers as a measurable photocurrent. The responsivity of the system, which is linear with the optical irradiance, can be controlled either by adjusting the frequency applied to the SAW transducer, or by modifying the RF power. The high specificity of the sensing mechanism renders high quality factors.

Different applications may be foreseen, from high performance detectors (2D arrays, multicolor detectors) and imaging devices [11], to acousto-optical modulators and opto-chemical sensors, demonstrating the many synergies resulting from the integration of SAW devices and optoelectronics.

All these applications can be envisaged regardless the piezoelectric semiconductor used. Furthermore, the epitaxial growth techniques allow the fabrication of low dimensional (e.g., multi-quantum well) heterostructures, in which combine the tailoring of the absorption edge with the manipulation of SAW modes by means of acoustic waveguides.

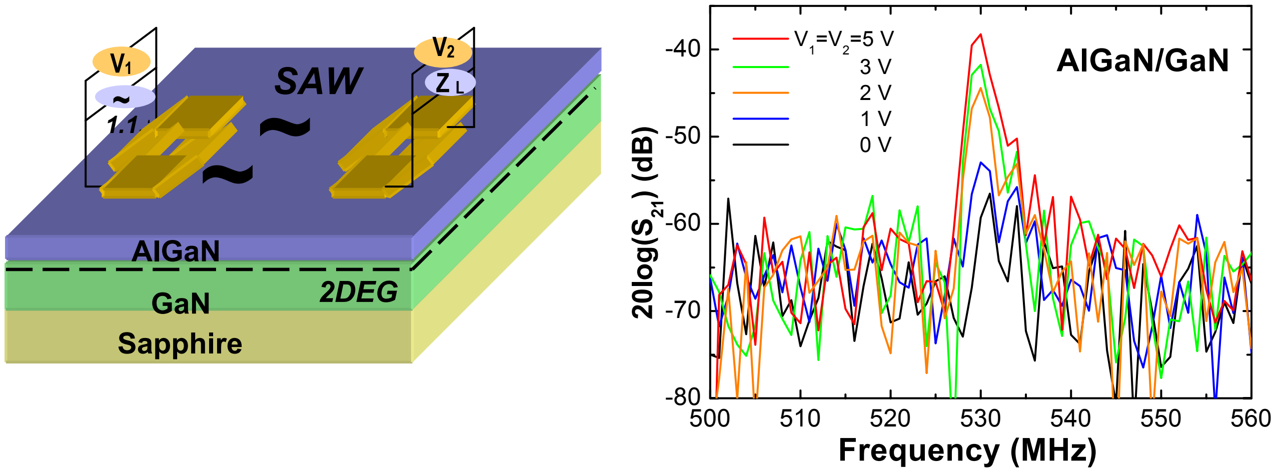



***Figure 5.*** *Experimental set-up for the operation of the SAW-2DEG DC-controlled filter (left), and transfer function for different DC bias applied to both IDTs (right).*

## INTEGRATION OF SAW WITH 2DEG HETEROSTRUCTURES

Typically, SAW devices are fabricated on insulating material, since no electromechanical coupling is allowed in charged materials. A few studies have reported SAW devices using gate control in 2DEG heterostructures, e.g., the hybrid AlGaAs/GaAs on $LiNbO_3$ structure, by means of placing the IDT outside the mesa containing the electron gas [12]. We have demonstrated a novel degree of device control when using an AlGaN/GaN 2DEG heterostructure as the piezoelectric layer, based on the charge control by gated IDTs [13] using Pt/Ti/Au or Ni/Au IDTs. The outstanding property of this novel device configuration is the tunability of the insertion losses of the resulting SAW filter with external voltages applied to the interdigital transducers (IDTs) [14].

The operation scheme is shown in Fig. 5: in addition to the RF signal and load in the respective input and output IDTs, both transducers are biased by independent external voltages. The device does not show any filter behaviour if no external voltage is applied: the charge of the space charge regions underneath the Schottky contacts and the 2DEG charge screen the piezoelectric fields preventing the acousto-electric transduction in the IDTs. However, when external voltages are applied to both IDTs, a filter-like transfer function is recovered (see figure 5): the DC voltages modify the space charge regions between adjacent fingers, and an effective acousto-electrical transduction takes place. The bias needed to control the devices, between 1 and 2 V for all the studied devices, seems to be related to the electrode barrier height. On the other hand, the filter response, narrower and asymmetric as compared to that of conventional SAW filters, is under study.

This new device can be integrated into existing circuits and systems. For example, GTC (Gain Time Control) or STC (Sensitivity Time Control) circuits for radar applications, which require a time-dependent control of the amplitude response of the system, can be easily implemented with this voltage controlled filter. However, the minimum insertion losses must be reduced for this application. Other novel applications can be foreseen, like integration of SAW technology with microwave electronics based on AlGaN/GaN HEMTs, and acusto-electric modulators and sensors based in this DC controlled filter.

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## 6.5 *InN layers grown on Silicon substrates by Plasma-Assisted Molecular Beam Epitaxy*

The development of the III-nitrides semiconductors (GaN, AlN and InN) has been spectacular during the last decade with great advances for optoelectronic devices operating in the green-blue and ultraviolet range. The contributions from the Institute of Systems based on Optoelectronics and Microtechnology (ISOM) during these last years in the nitrides-based optoelectronic field have been focused on the growth, by plasma-assisted molecular beam epitaxy (PA-MBE), characterization and development of different devices such as: AlGaN-based ultraviolet photodetectors, blue-green GaN/InGaN-based light emitters diodes (LEDs) and AlN-based surface acoustic waves (SAWs) filters. All these were grown using different types of substrates like: silicon, sapphire ($\alpha$-$Al_2O_3$), GaN-templates and SiC/Si. During this last decade the scientific community working with nitrides has dedicated much less attention to the binary InN than to GaN and AlN, mostly due to the difficulties to obtain high crystal quality InN. It is worthed to mention that during this period of time a band gap energy for InN of approximately 1.9 eV was attributed and generally accepted. However, the recent determination of the band gap energy of wurtzite InN, as low as 0.7 eV [1], has opened a new field, extending the range of operation of III-nitrides into the near-infrared region of the electromagnetic spectrum. Among the new applications, a very attractive one is the possibility of designing and fabricating multijunction solar cells based on the $In_{1-x}Ga_xN$ ternary alloy system, covering a wide energy range from 0.7 eV (InN) to 3.4 eV (GaN), and thus providing a near-perfect match to the solar energy spectrum, which will greatly improve the efficiencies of these devices. Another interesting application might be the development of lasers diodes based in multi-quantum well structures of InGaN/GaN for optical-fiber communication-systems operating at wavelengths from 1.3 to 1.6 µm. These new devices could replace the GaInNAs-based devices, which have the inconvenient of using toxic elements like arsenic.

The ISOM has recently initiated a new field of research inside the III-Nitrides, dedicated to the MBE growth, characterization and fabrication of InN-based optoelectronic devices. The main difficulty for the preparation of high quality InN is still the lack of a suitable substrate material. The lattice mismatch between InN and the two most common substrate materials used for nitrides, $\alpha$-$Al_2O_3$ (0001) and 6H-SiC (0001), is about 25% and 15% respectively. An interesting alternative may be the use of Si(111) substrates, with a lattice mismatch of 8%. The ISOM has long experience on the growth of III-nitrides on Si(111) substrates [2,3]. Heteroepitaxy of III-Nitrides on Si is in general feasible due to the possible lattice matching of hexagonal wurtzite epitaxial films and a diamond Si(111) crystal face. Besides the availability of large size wafers (up to 12 inches diameter), low cost, and excellent crystal quality of Si, it also posseses excellent material characteristics such as doping properties, cleavability, good thermal conductivity (approximately 3 times larger than sapphire), and mature processing techniques. All these advantages open up interesting applications of InN including the potential integration with Si technologies.

The work performed up to the date has been focused on the effect of the growth temperature and the use of different buffer layers on the morphology and properties of InN layers grown on Si(111) substrates [4,5]. AlN and InN buffer layers have been studied as well as the most critical parameter affecting the III/V ratio such as the substrate temperature in the range of 400-550 ºC. A series of growths varying the substrate temperature, the amount of active nitrogen and the In molecular flux indicate that for growth temperatures above 500 ºC, disociation of InN takes place at the surface of the grown layer producing In droplets. The fact that InN disociation takes place at a lower temperature than desorption of the III-element needs to be considered carefully in order to optimize the growth parameters.

High temperature AlN and low-temperature InN buffer were employed for the growth of InN layers at a substrate temperature in the range 460-475 ºC, with a typical growth rate of 0.8 μm/h. In both cases, N-rich conditions lead to columnar-like InN crystals while layers grown towards In-rich conditions exhibit a compact morphology (Figure 1).

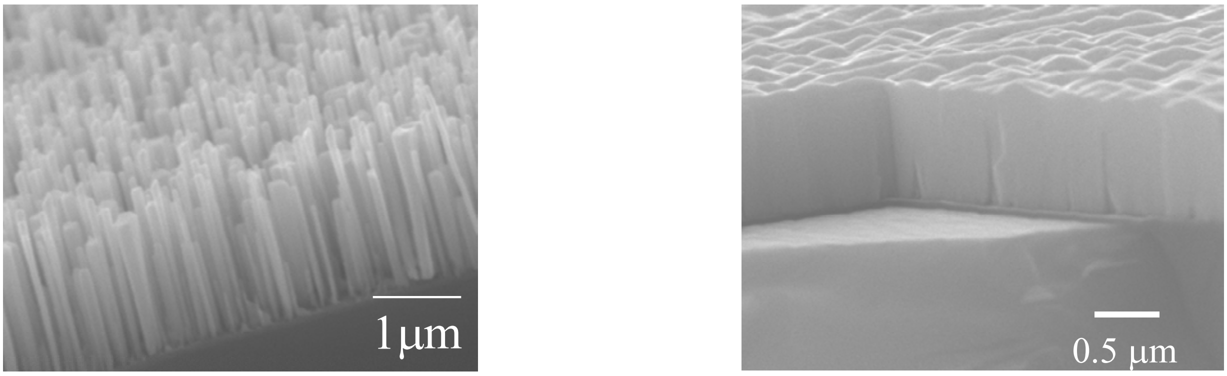


***Figure 1.*** *Scanning electron microscopy (SEM) photographs of InN layers grown at 475ºC with the same amount of active nitrogen but with increasing In molecular fluxes (given by beam equivalent pressures), going from N-rich to In-rich conditions: (a) 2.5 e-7 Torr and (b) 6.0 e-7 Torr.*

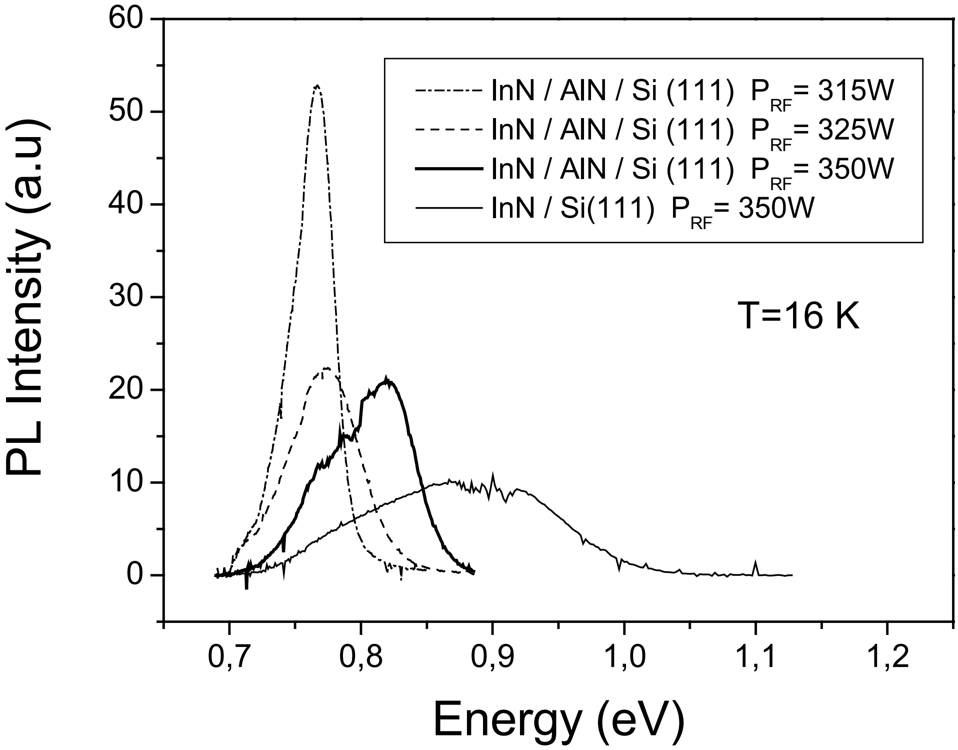


***Figure 2.*** *Low temperature photoluminescence spectra of columnar InN layers grown at 500ºC with a fixed In-flux and different nitrogen plasma powers.*

Optical properties have been measured by low temperature photoluminescence (PL) techniques showing a higher PL intensity for the columnar samples as compared with the compact ones, with a full width at half maximum (FWHM) down to 34 meV, indicative of a high crystal quality (Figure 2). In all cases, the emission is observed between 0.74 and 0.87 eV, in agreement with the narrow InN band gap value recently reported [1]. No emissions are observed for higher energies in any of the grown films. The optical properties are also analysed by absorption measurements (FTIR) with a clear correlation with the emission spectra.

High resolution X-ray diffraction rocking curves from compact samples grown at 475 ºC on AlN buffer layers show a FWHM of the InN (0002) reflection down to 682” (Figure 3). Samples grown at higher temperatures and/or with InN buffer layer exhibit a substantial broadening of this reflection. The surface roughness of the grown samples is currently being optimized by means of migration enhanced epitaxy techniques and/or by lowering the high current growth rate (0.8 μm/h) adjusting the III/V ratio to maintain a slightly In-rich condition.

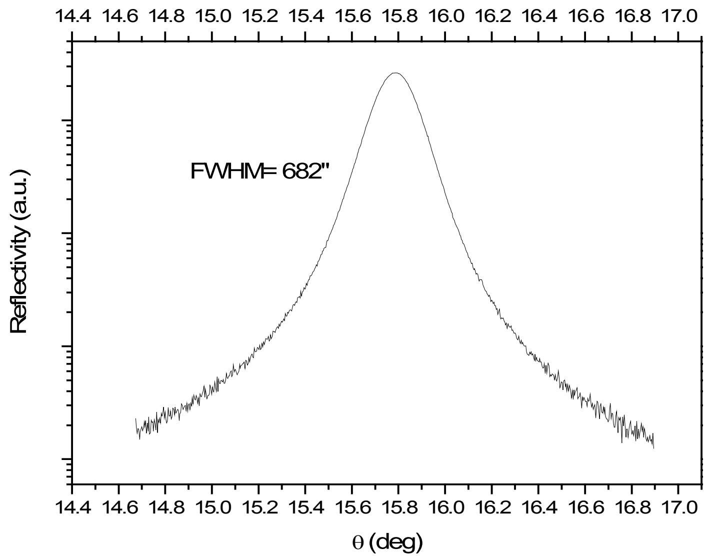


***Figure 3.*** *Rocking curve of the InN(0002) reflection of a compact InN layer grown at 475ºC on a AlN-buffered Si(111) substrate with a FWHM of 682 arcsecs.*

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## 6.6 *Nanostructures and Nanodevices based on Nitrides of group III*

The Nitrides of group III (GaN, AlN, InN) are novel semiconductor materials that offer the possibility to fabricate optoelectronic and electronic devices with properties and performance well beyond those of the standard devices. That is the case of electroluminescent diodes (LED), lasers (LD) and detectors in the blue and UV range (1-3); high speed and high power transistors based on triangular Quantum Wells (QW); and high frequency filters based on Surface Acoustic Waves (SAW)(4,5). The high energy bonds in these materials provide a high thermal stability and capability to withstand chemical aggressive and corrosive environments. This is why the AlGaN/GaN HEMT transistors, aside from reaching very high operation frequencies (>50GHz), they also dissipate quite high power densities, above 10 times higher that those from similar devices based on Arsenides. The III-Nitrides, having a wide direct band gap, and allowing the growth of ternary (InGaN y AlGaN) y quaternary (InAlGaN) alloys, represent the ideal material system to cover a broad spectral range (0.7eV for InN up to 6.2eV for AlN) for optoelectronic applications, either in emission or detection, from infrared to deep UV.

Since the first III-Nitrides commercial devices (blue LED), 10 years ago, the search for new techniques to improve the crystal quality of these materials kept on. The synthesis of bulk GaN by conventional methods is limited by its elevated melting point (2800 K) and the extreme nitrogen vapor pressure needed (4 GPa)(6). Nowadays, there are no adequate commercial substrates for homoepitaxy, then, the typical epitaxial techniques, Molecular Beam Epitaxy, (MBE) and Metal-Organic Vapor Phase Epitaxy, (MOVPE) proceed on an heteroepitaxial way, and the crystal quality depends strongly on the mismatch between the lattice and thermal expansion coefficients between the epilayer and substrate. Due to these mismatches, the epilayer accumulates biaxial strain that, upon relaxation, generates a high density of dislocations (>109cm$^{-3}$) that degrade substantially the optical and electrical properties of the material, and thus, the device performance. There are methods to minimize these effects using buffer layers either simple or elaborated multilayer (7-9).

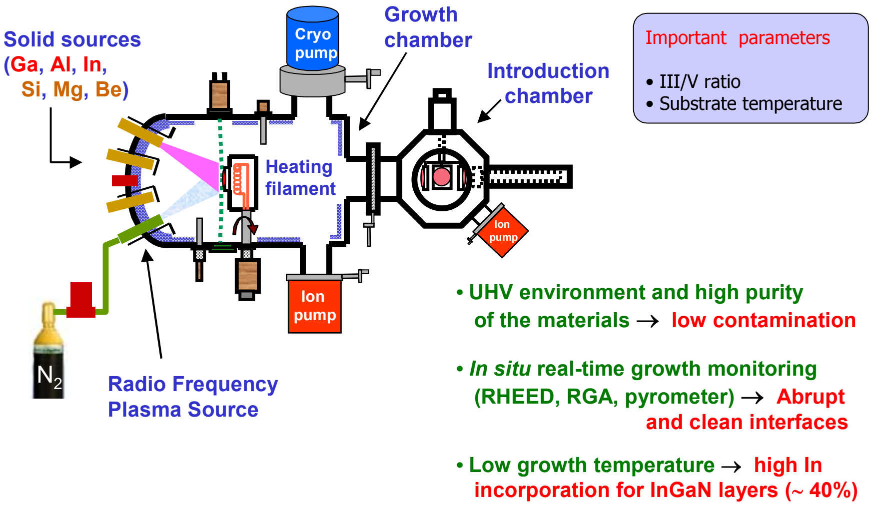


***Figure 1.*** *Molecular Beam Epitaxy System using a Nitrogen RF-Plasma source to grow III-Nitrides.*

The recent development of self-assembled Nanostructures of III-Nitrides has attracted the interest of many researches in the scientific community, and it poses an alternative way to overcome the difficulties inherent to the heteroepitaxial growth of III-Nitrides. Different studies addressed in depth the growth of GaN and InGaN Quantum Dots (QDots)(10,11), as the basis to fabricate laser devices where the strong carrier localization improves the optical efficiency and reduces the threshold current density (12).

An alternative way to the QDots is the use of InGaAlN Nanostructures (Nanocolumns, Nanopillars) that may allow the fabrication of arrays of NanoLEDs and Nanolasers covering a wide spectral range, from IR to deep UV, as well as photon sources (single-mode solid-state single photon source, S4P). The last, being nowadays a quite ambitious objective given their potential for secure telecommunication systems based on quantum cryptography. The possibility to fabricate Nanocavities by a self-assembled process, in addition to simplify the technological processing, it improves substantially the device performance due to the strong reduction of the damage produced by standard dry etching (RIE)(13,14).

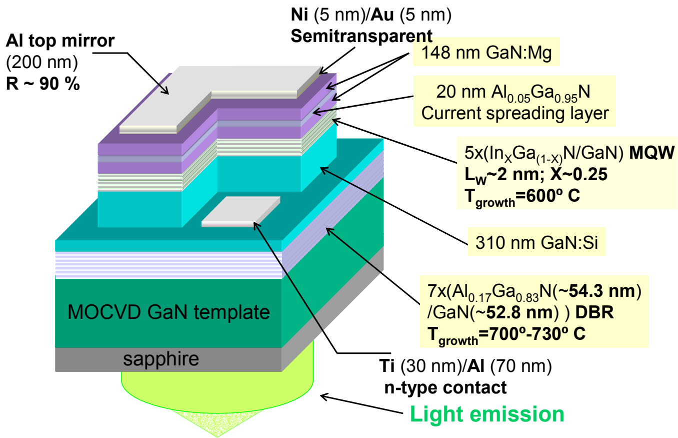


***Figure 2.*** *Layer structure of a Resonant Cavity LED emitting at 510 nm.*

The first Nanostructures of α-$Al_2O_3$ and SiC appear during the 60's and 70's (15,16), and in 1964, Wagner y Ellis achieved the synthesis of Si Nanocolumns (Si whiskers with 100nm Ø) from an euthectic melt of Au in a Si droplet, a process that has been named as vapor-liquid-solid (VLS) (17). The first GaAs Nanocolumns grown by MOVPE evidenced the presence of a Ga droplet on their top, that points to the VLS growth mechanism, though in this case there is no need of any impurity (18). For compound semiconductors it has been suggested that the excess of one of their elements may act as a precursor for the Nanocolumnar growth, though this is still an open question. The potential for applications of the Nanostructures has been quickly recognized by many research groups (19,20).

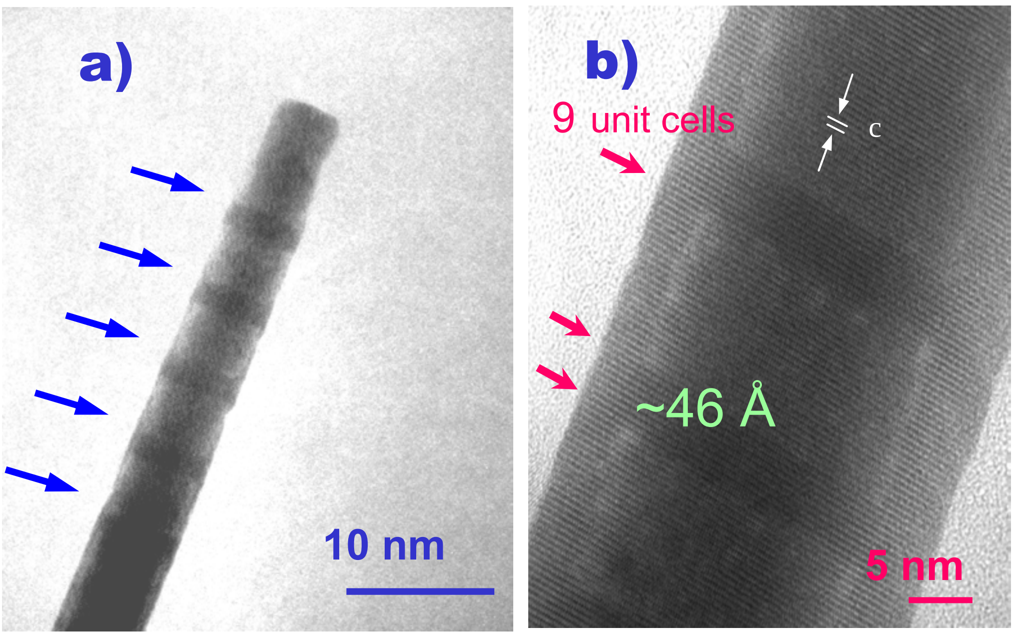


***Figure 3.*** *a) TEM micrograph of an AlGaN Nanocolumn with 5 GaN Quantum Disks. b) High resolution view of a)*

The first GaN Nanocolumns appear at the end of the 90's (21-23) in a rather fortuitous way, having diameters between 50 and 150 nm, not small enough as to evidence lateral quantum confinement effects, due to the electron effective mass values in these materials. However, the enormous potential of these Nanostructures is immediately recognized, because they are free from extended defects, in contrast with compact layers of the same materials. Their exceptional crystalline quality promotes them as ideal candidates for optoelectronic devices and to study basic transport properties, given the reduced scattering efficiency (hot-electron).

The GaN Nanocolumns exhibit a very high optical efficiency, having luminescence intensity several orders of magnitude higher than the compact GaN layers (23,24). The possibility to grow Nanocolumnar Heterostructures, including Quantum Wells and Discs of AlGaN and InGaN embedded in Ga(Al)N Nanocolums will produce a strong carrier and optical confinement, resulting in quite efficient active regions for optoelectronic devices (emitters and detectors). Including Bragg reflectors into these Nanostructures will lead to develop Nanocavities, where to study the basics on polariton effects (exciton-photon coupling) (25-27). The Nanocavities provide the core structure to develop efficient lasers (zero theoretical threshold), Resonant Cavity LEDs, and VCSELs (Vertical Cavity Surface Emitting Laser). The ability to grow Nanostructures and Nanodevices on Si(100) substrates, that is, the typical substrate orientation for Integrated Circuit Technology, opens a new field of real integration of optoelectronic devices with C-MOS circuitry.

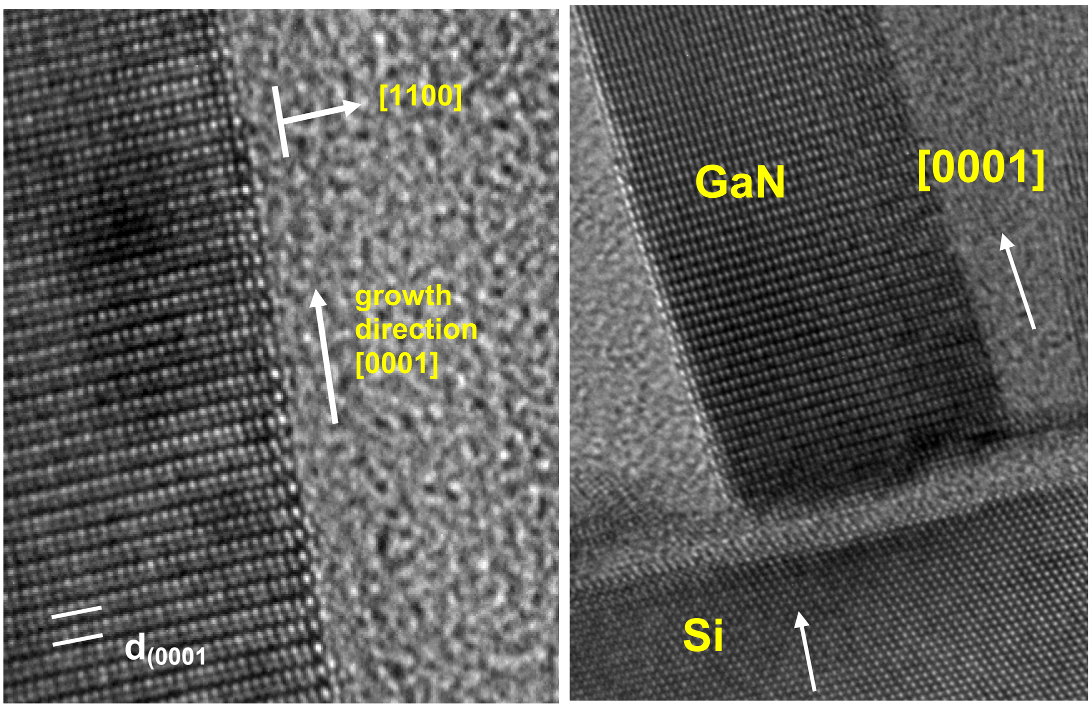


***Figure 4.*** *High resolution TEM images of a GaN Nanocolumn with details about the lateral surface and the interface with the Si (111) substrate).*

The III-Nitrides have also specific transport properties, like a relative low effective mass for electrons (0.11 InN; 0.2 GaN; 0.48 AlN) and a high electron saturation velocity (430 km/s InN, 310 km/s GaN, 170 km/s AlN), that can be exploited to fabricate electronic devices with high performance and functionality. These heterostructures at Nanometric scale may lead to the observation of ballistic transport; laser emission at THz frequencies under moderate electric fields (5–20 kV/cm); and negative differential resistance at threshold fields as low as 7 to 50

MV/m (well below the breakdown field about 100 MV/m). Oscillators at THz frequencies have, among other applications, a great interest in mobile communications.

Other important properties of III-Nitride heterostructures rely on the high piezo and piroelectric fields, that bring unusual properties for novel devices. For instance, in heterojuction field effect transistors (HFETs) the spontaneous and piezoelectric polarization fields (intrinsic an strain-related) allow to reach very high electron sheet densities in the channel without the need of any intentional doping.

**The Institute for Optoelectronic Systems and Microtechnology (ISOM) at the ETSI Telecomunicación (U. Politécnica de Madrid) is pioneering at international level in developing self-assembled Columnar Nanostructures based on III-Nitrides grown by MBE.**

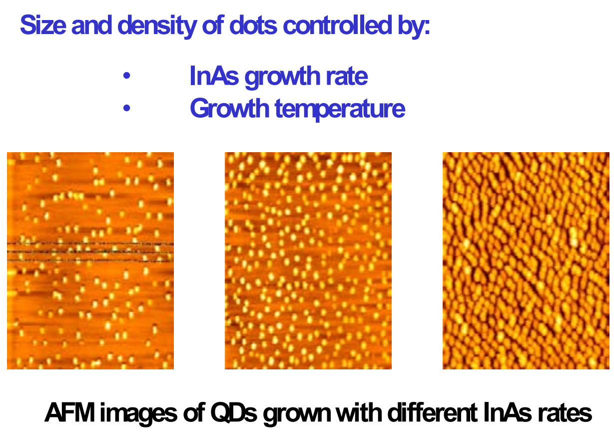


***Figure 5.** InAs Quantum Dots observed by AFM Microscopy.*

Among the ISOM activities in this field, it is worth to mention the work on UV LED emitters with a Resonant Cavity (RCLED), that cover the spectral range between 360 to 280nm and optimize their efficiency by means of a resonant cavity with Bragg reflectors and active regions with Multiple Quantum Wells (MQW). These UV-LEDs are grown by Molecular Beam Epitaxy assisted with a RF plasma source (rf-PAMBE), whose schematic diagram is shown in figure 1. The ISOM also works on the development of arrays of NanoLEDs with a structure o a conventional RCLED (figure 2) but using (In)GaN Quantum Discs embbedded in AlGa(In)N Nanocolumns. A TEM image of Duch a Nanostructure, a AlGaN Nanocolumn with five GaN QDisks is shown in figure 3. This micrograph reveals an extraordinary crystal quality, a perfect orientation along the growth direction (0001) and the clear atomic layer sequence with atomically abrupt interfaces (figure 4). The ISOM develops UV detectors based on Nanoestructures covering the spectral range between 450-300nm, for bio-photonics, medical and hydrocarbon combustion control applications. Their active region is made of InGaN QWs several nm thick. In the infrared region, we develop InGaAs(N) QDot detectors based on "dilute Nitrides" with a low N percent (2 to 3%), which is enough to lower the bandgap down to the 1,3-1,5 micron range. Figure 5 shows AFM (Atomic Force Microscopy) pictures where the size and density of InAs QDots can be observed as a function of the growth conditions.

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## 6.7 *AlGaN/GaN HEMT Transistors*

**INTRODUCTION**

High electron mobility transistors (HEMTs) based on GaN are today the most promising microwave transistors for high power, high voltage, high temperature operation. Nitride-based devices are able to work in hostile environments, and thus substantial weight savings can be made in aircrafts and spacecrafts.

However, present limitations of GaN-based HEMTs come from both material problems and from a non-mature processing technology. It is found that dominant surface-related problems, buffer leakage, parasitic series resistances effects, significant carrier trapping, large non ideality factors of the gate I-V characteristics, etc. are penalizing device performances. Thus, new improvements in substrates and in processing technology are required. Besides, facing the prospective of a future transfer to industrial production, not only improved and reproducible processing technology is needed, but adequate organization/planning processing, wafer monitoring and mapping techniques, and a good feedback of such results to wafers developers/producers are also required. For example, the whole area of surface cleaning, etching, passivation and minimization of wafer defects still require improvements to ameliorate the RF behavior of present GaN HEMTs.

The main objective of this work has been the fabrication and characterization of micron and submicron gate HEMT transistors to be used in the development (by SSR Dept. ETSIT-UPM, Prof. J. Grajal) of L band (1-2 GHz) and the X band (8-12.4 GHz) amplifiers (Fig 1). High electron mobility transistors (HEMT) fabrication is divided into four main parts: AlGaN/GaN heterostructures, transistor processing, electrical characterization and process control.

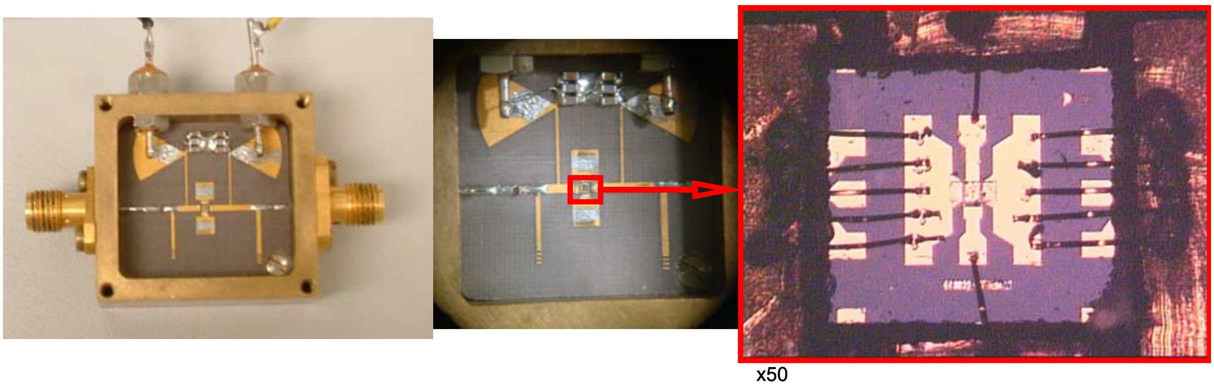



***Figure 1**. View of HEMT microwave transistor fabricated at ISOM and RF amplifiers developed at SSR-UPM. Transistor chip is about 1 mm$^2$*

**AlGaN/GaN HETEROSTRUCTURES**

AlGaN/GaN wafers used to fabricate transistors were grown by MBE at ISOM, and also came from research institutions (Ghent University, and CHREA-CNRS, France), as well as from semiconductor companies (QinetiQ, UK and Sensor Technologies, USA), all fabricated using MOVPE techniques. In order to check material quality for the fabrication of the HEMTs, AlGaN/GaN heterojunctions were characterized by photoluminescence (PL), high-resolution x-ray diffraction (HRXRD) (see Figure 2), C–V, and Hall Effect measurements. As an example, of the characterization Ghent University wafers, produced interesting results. These samples were grown

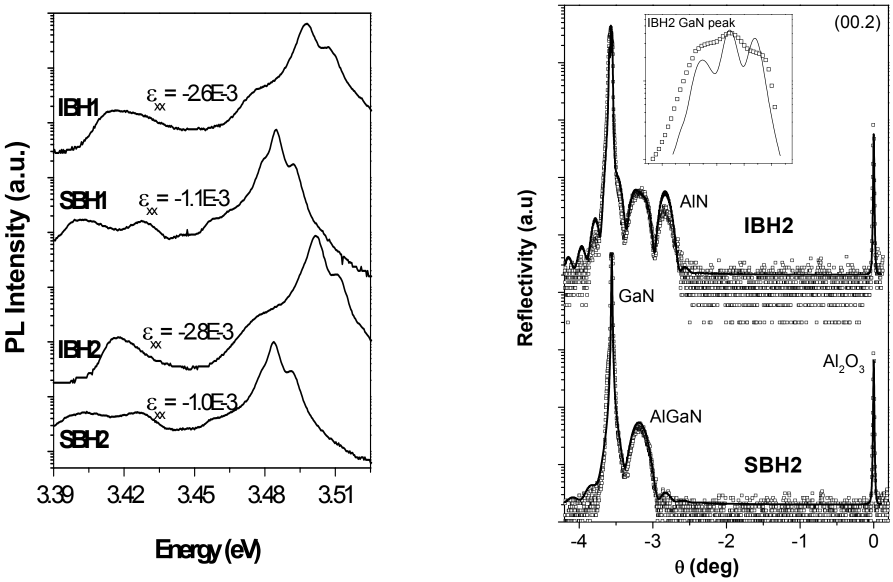



***Figure 2.*** *Photoluminescence (left) and HRXRD (right) spectra for samples with (IBH) and without (SBH) AlN interlayers embedded into the GaN semi-insulating buffer.*

with two AlN interlayers embedded into the GaN semi-insulating buffer of AlGaN/GaN high electron mobility transistors (named IBH), in comparison with standard heterostructures without AlN interlayers (named SBH). The AlN interlayers generate a compressive strain in the GaN topmost layer, which slightly reduces the total polarization field, but most important, it prevents the AlGaN barrier from plastic relaxation. The final result is an enhanced polarization field with respect to standard heterostructures, providing an increased channel carrier density and pinch-off voltage. [1].

## PROCESSING TECHNOLOGIES AND TRANSISTOR FABRICATION

- <u>Mask optimization</u>

From the beginning of the AlGaN/GaN transistors activities at ISOM, three mask sets have been developed. All of them took into account the acquired experience in the development of the final devices, to be able to optimize DC and RF characteristics. Major improvements include new ohmic and Schottky contacts geometrical design, and the possibility of processing submicron and multifinger gate contacts.

- <u>Isolation techniques: mesa etching</u>

From each sample processed from a wafer, 120 transistors can be obtained. To ensure electrical isolation of each device, mesa etch is performed by dry etching techniques. From the first results using Ar based Ion Beam Milling (~ hundreds of kΩ) we switched to Cl based Reactive Ion Etching reaching isolation resistances of about GΩ.

- <u>Ohmic contacts</u>

Drain and source contacts are critical in this type of transistors due to de difficulties in obtaining good ohmic contacts in GaN and AlGaN devices. The main objective in this step is to obtain contact resistances below 1 Ω·mm. Different metals and metalization schemes have been used, as well as different rapid thermal annealing times and temperatures. First results using Ti, Al, Ni, Pt and Au provided contact resistances as high as 10 Ω·mm. At this time reproducible values of 0.5 Ω·mm are obtained in transistor processing.

- <u>Photolithography and Schottky barriers (gate contacts)</u>

Following the same procedure as with the ohmic contacts, studies on different metals and metallization schemes were conducted in order to obtain the best Schottky barrier. Once this metals were optimized through gate and Schottky diodes CV and IV measurements, we focused on obtaining sharp edges in the metalization of 1 µm length gates. Moreover, to be able to obtain gate lengths below 1 µm, an Electron Beam Lithography system has been set up with an existing Scanning Electron Microscope. This processing technique provided gates with lengths as short as 0.15 µm, as Figure 3 shows.

- Surface passivation

This is one of the most critical steps in AlGaN/GaN transistors due to the so-called current collapse which mainly is due to a reduction of the drain current under dynamic or RF conditions [2-5] This current collapse is reduced and almost disappears with the inclusion of a thin insulating layer on the AlGaN surface. From our first studies we decided to use Plasma Enhanced Chemical Vapor Deposited (PE-CVD) SiN as the passivating layer. Furthermore, in order to optimize SiN layer, it was characterized using several techniques like ellipsometry, etch rate, Fourier Transform Infrared spectroscopy (FTIR), plastic deformation measurements and electrical measurements.

- Chip dicing

The final processing step is chip dicing to be able to use the transistor as an amplifier. Therefore, each transistor must be separated from the rest ones by dicing. This simple procedure becomes complicated when dealing with a substrate as sapphire. To surpass this problem an automatic precision dicing machine was set up at ISOM-UPM, producing clean separation between transistors. Moreover, our last mask set was designed taking into account this final step to avoid damaging nearby transistors.

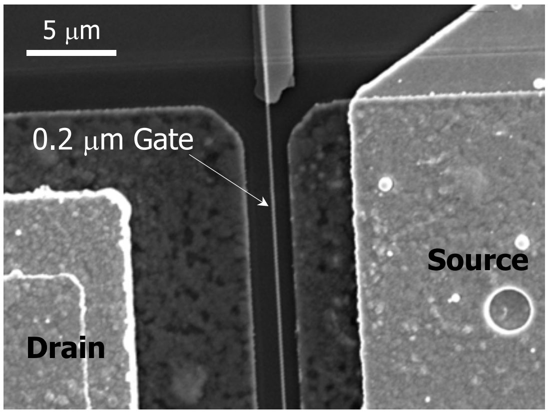


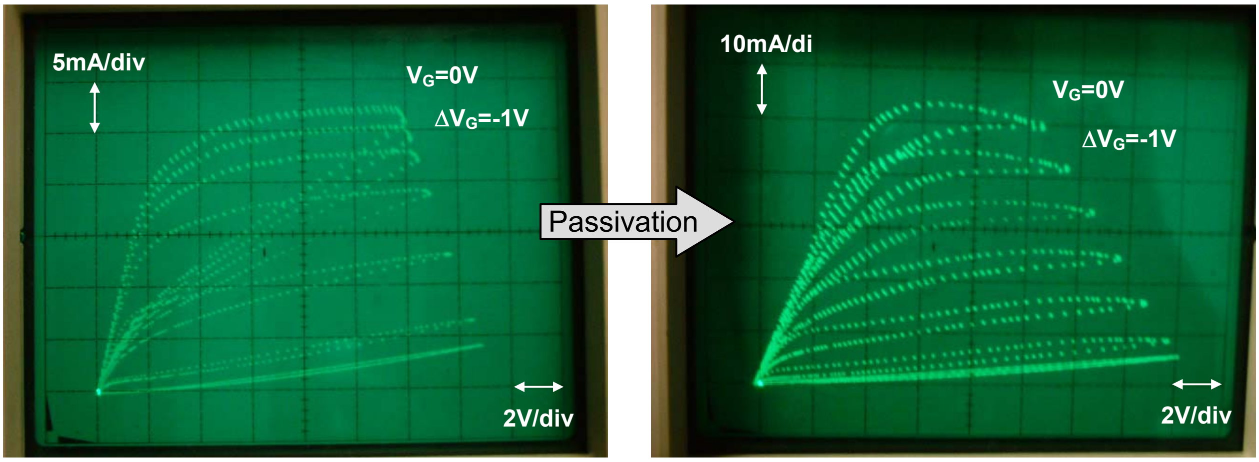

***Figure 3.*** *SEM micrograph of a submicron transistor, showing 0.2 µm gate length.*

## DC AND RF TRANSISTORS CHARACTERIZATION

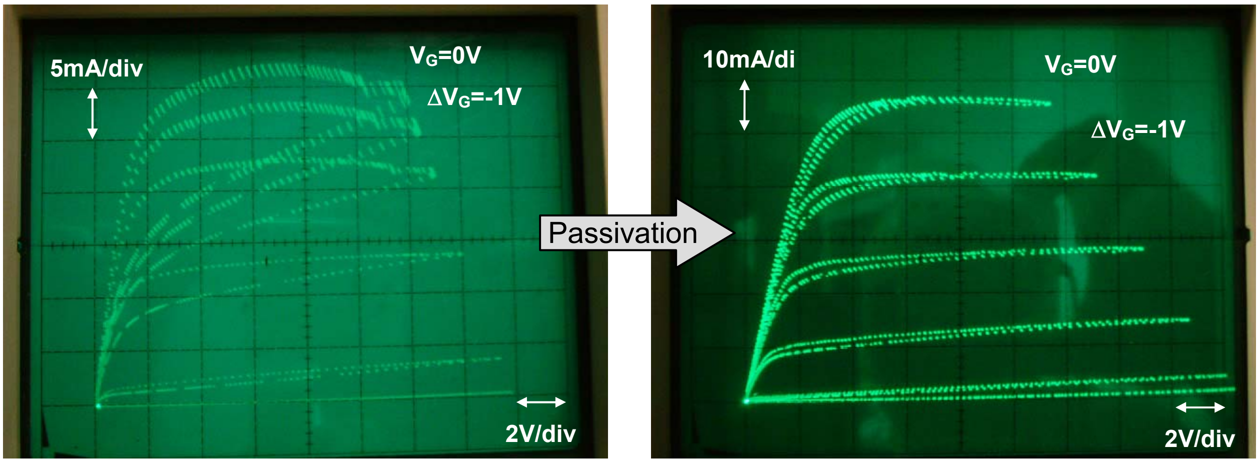
Figure 4 depicts pulsed measurements of some of the processed samples, showing the positive effects of SiN passivating layers. Table I summarizes some DC results for the same samples in Figure 4, and using SBH and IBH heterostructures. High $I_{ds}$ and $g_m$ values were achieved.

***Table I.-*** *DC characteristics of the processed samples.*

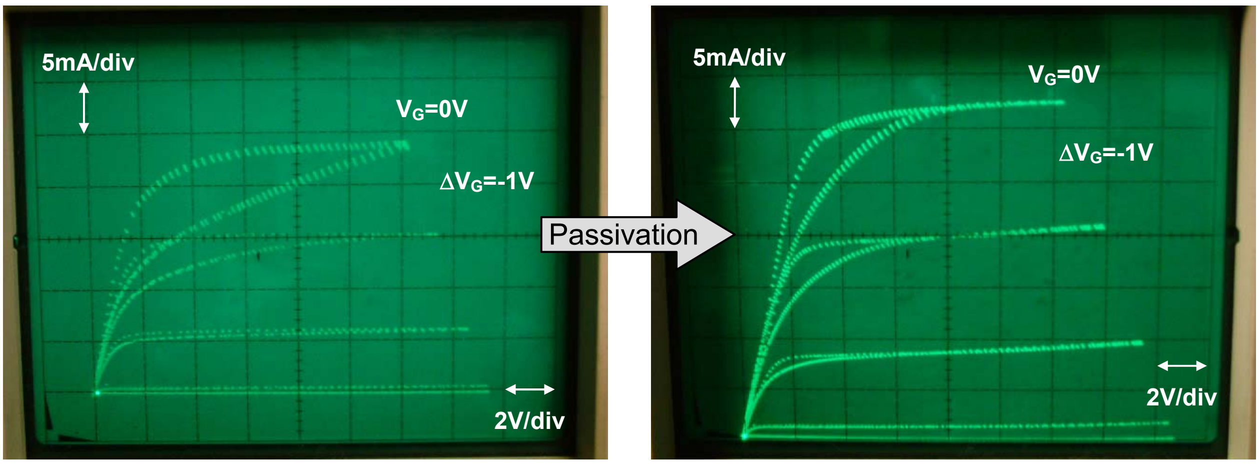
| Sample | $L_G$ (µm) | $W_G$ (µm) | $I_{DSmax}$ mA/mm | $g_{m\ max}$ mS/mm |
|---|---|---|---|---|
| Sample 1 | 0.2 | 150 | 1070 | 170 |
| | 1.3 | 150 | 840 | 160 |
| Sample 2 | 0.2 | 150 | 280 | 65 |
| | 1.3 | 150 | 470 | 120 |
| Sample 3 | 0.2 | 150 | 670 | 140 |
| | 1.3 | 150 | 440 | 160 |
| SBH | 0.2 | 75 | 1066 | 213 |
| | 1.0 | 75 | 1066 | 220 |
| IBH | 0.2 | 75 | 1466 | 266 |
| | 1.0 | 75 | 1253 | 250 |




Sample 1. $L_G$=1.3µm - $W_G$=150µm ($\Delta I_{DSmax} \approx$ 95%)




Sample 2. $L_G$=1.3µm $W_G$=300µm ($\Delta I_{DSmax} \approx$ 70%)




Sample 3. $L_G$=1.3µm $W_G$=150µm ($\Delta I_{Dsmax} \approx$ 35%)

***Figure 4.*** *DC Characteristics before and after passivation*

Moreover, RF measurements (SSR) were performed in some selected devices to obtain their high frequency behaviour. Figure 5 shows $f_T$ as a function of the gate length for some of the samples. In submicron devices, with non-optimized standard strip gates (high gate resistances), $f_T$ of tens of GHz were regularly obtained.

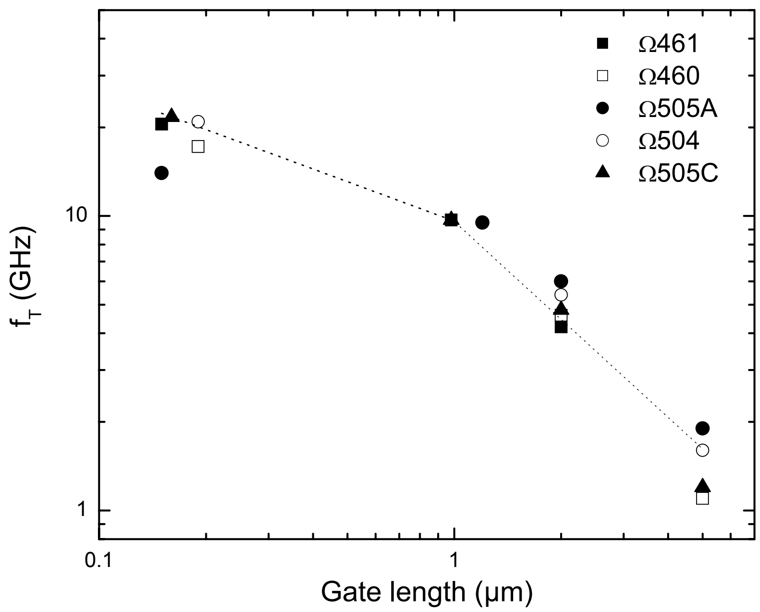



***Figure 5.*** *RF performance of 1, 2 and 5 μm and submicron gate HEMT devices for different samples.*

***Acknowledgements***

*This project is being jointly developed by ISOM, CIDA-Defense Ministery and INDRA Systems. Processing facilities at CIDA in relation to dry etching and SiN deposition have played a key role. INDRA scientists working at ISOM facilities have significantly contributed to develop some of the HEMT processing steps.*

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# 6.8 Study of the Magnetic Reversal Processes in Microstructures of Amorphous Co-P Magnetic Alloys

## INTRODUCTION

The possibility of controlling the magnetic behavior of patterned films has increased in the last few years the interest in this kind of lateral structures (1-4). Among the techniques for fabricating these structures the combination of lithography and electrodeposition has revealed like one of the most used.

The aim of this work is to study the magnetic properties of planar arrays of CoP monolayer microstrips and their influence in CoP multilayer films grown over them. Both of the structures were obtained by electrodeposition. CoP amorphous alloys have very soft magnetic properties which have recently led to the fabrication of microsensors (5) and microinductors (6).

Since the early eighties it is known that electrodeposited amorphous CoP films have an easy or hard axis of anisotropy perpendicular to its plane depending on whether they are monolayer or multilayer (7,8). The combination of the structures that we study in this work shows the influence of the perpendicular anisotropy of microstrips on the multilayer films.

One of the most important results of this work is that the magnetization reversal processes of the multilayer surface depend on its thickness and the direction with respect the long microstrip axis. The magnetic domain structures have been studied by means of magnetic force microscopy.

## SAMPLES AND EXPERIMENTAL TECHNIQUES

The structures in which this study has focused are planar arrays of microstrips of monolayer CoP alloy, and these arrays covered by multilayer CoP films. The arrays are formed by 5 mm-long and 100 µm-width microstrips, separated by a distance of 100 µm (fig. 1). The thickness of the microstrips ranges from 2 to 8 µm. The area of the whole array is 5×5 mm$^2$. The films grown on the arrays are multilayers of CoP alloys with a layer thickness of 10 nm. The thickness of the multilayer ranges covers from 1 to 16 µm.

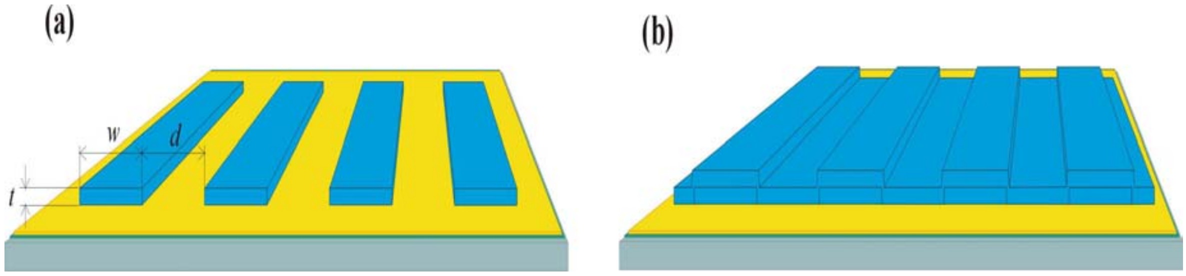


***Figure 1.*** *Diagrams of (a) a planar array of microstrips and (b) an array covered by a film.*

The hysteresis loops have been obtained by two different techniques, magneto-optical Kerr effect and vibrating sample magnetometries. The sooner gives information of the sample surface up to approximately 30nm depth, while the later provides information of the whole volume.

The magnetic characterization of the samples has been completed with the study of the magnetic domain structures by magnetic force microscopy.

## RESULTS AND DISCUSSION

### a) Array of monolayer microstrips vs. monolayer film

The magnetic properties of CoP monolayer films were widely studied in the early eighties. It is known since very long that films with a thickness bigger than a characteristic value have an easy axis of anisotropy in the normal direction to the sample plane. In this study we have obtained that the 75% vol. of a 2µm-thick monolayer film reverse its magnetization by a 90º spin rotation. This volume increases up to the 80% for a 8µm-thick film.

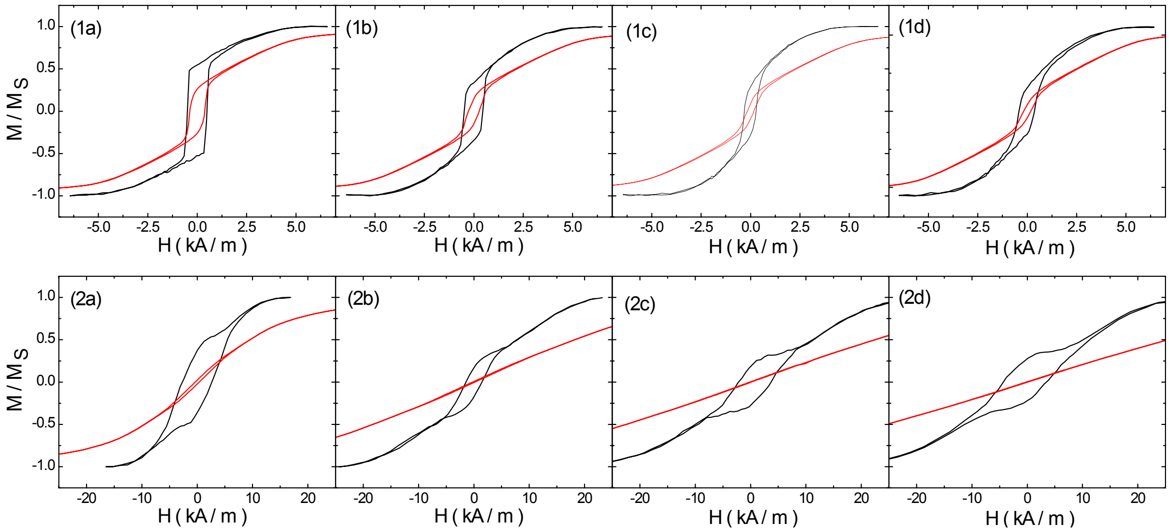


***Figure 2.*** *Hysteresis loops of planar arrays of monolayer microstrips with thicknesses of (a) 2 µm, (b) 4 µm, (c) 6 µm and (d) 8 µm, measured in (top) the longitudinal and (bottom) the transversal direction. The black loops correspond to the surface and the red ones to the bulk of the samples.*

Studying the magnetic properties of the arrays of monolayer microstrips, it can be seen that, while in the longitudinal direction the magnetic reversal processes (fig. 2, top) are nearly the same than in the film, in the transversal direction the processes are quite different (fig. 2, bottom).

As it was expected the demagnetizing factor in this direction is much bigger than in the film, what makes the anisotropy field in this direction increase. But the mean effect of the shape of microstrips in their properties is that the coercive field of the sample surface in the transversal direction is between 5 and 9 times the coercivity in the longitudinal direction.

The study of the magnetic domain structures on the sample surface is a very good complement for the magnetic characterization. The images of the microstrips obtained by MFM (magnetic force microscopy) exhibit structures of stripe domains which are due to the magnetic anisotropy normal to the surface (fig. 3). In these images it can be seen that the thicker the microstrips are the wider and wavier the stripe domains are. The stripe domain structures obtained in the remanence after applying a saturating field in the longitudinal and the transversal directions are the same but the direction of stripes which is the direction of the last field.

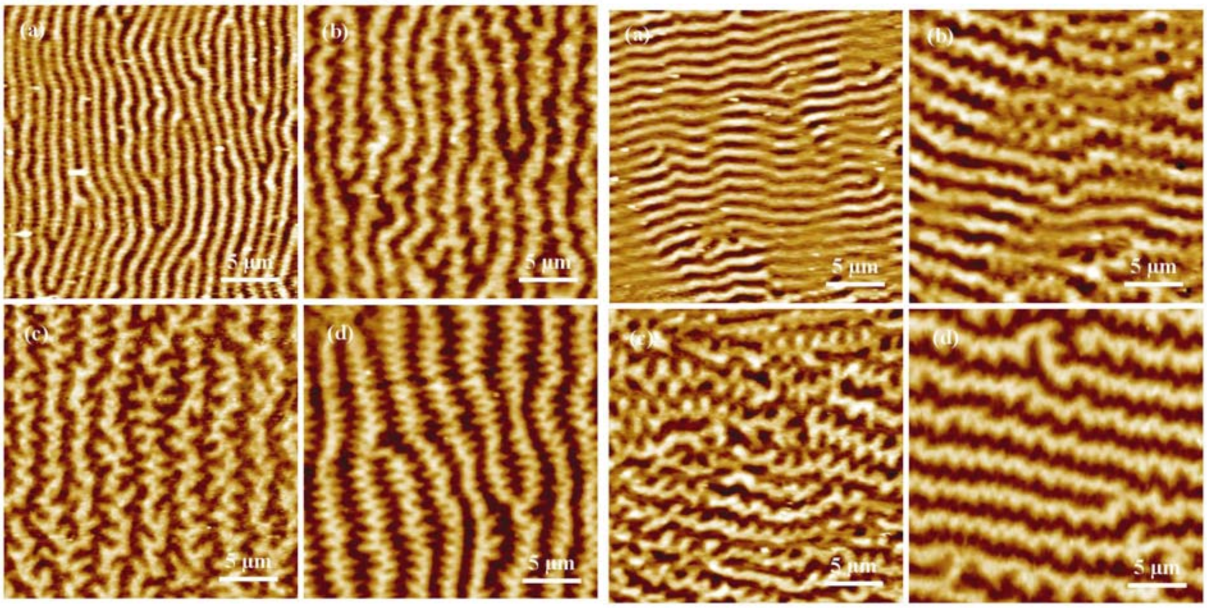


***Figure 3***. *MFM images of the magnetic domain structures of microstrips with thicknesses of (a) 2 µm, (b) 4 µm, (c) 6 µm and (d) 8 µm, obtained after applying a saturating field in (left hand) the longitudinal and (right hand) the transversal direction.*

When the *stripe* domains are normal to the microstrip edge new domains appears in the border for decreasing the width of the *stripes* (fig. 4).

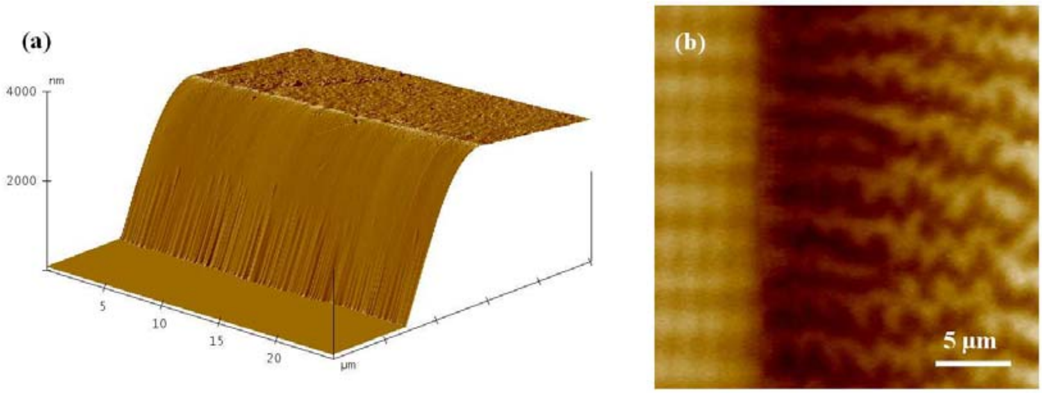


***Figure 4***. *Images of (a) the profile of a lateral edge of a 8 µm-thick microstrip and of (b) its magnetic domain structure after saturating it in the transversal direction.*

**b) Multilayer film covering an array of monolayer microstrips.**

The magnetization reversal processes in a CoP multilayer film grown over an array of monolayer microstrips depends strongly on its thickness. In these samples the parts of the film which are over the microstrips work closing the magnetic flux produced by the stray field of the stripe domains. This behavior makes the surface of the multilayer film have and inverted hysteresis loop when the film thickness is between 2 and 8µm (fig. 5)

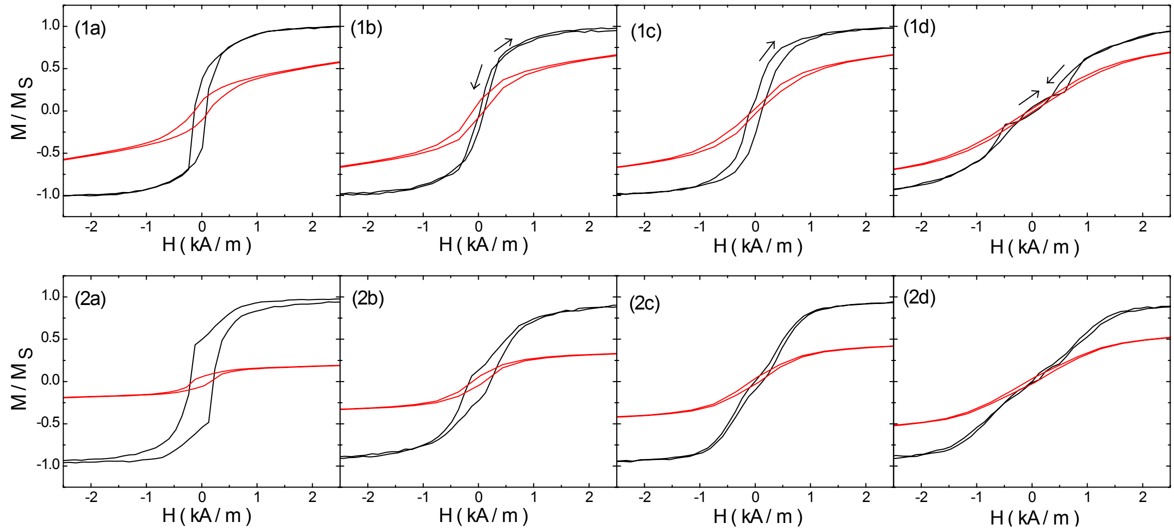


***Figure 5****. Hysteresis loops of multilayer films with thicknesses of (a) 1 µm, (b) 2 µm, (c) 4 µm and (d) 8 µm, grown over an array of 8µm-thick monolayer micorstrips, measured in (top) the longitudinal and (bottom) the transversal direction. The black loops correspond to the surface and the red ones to the bulk of the samples.*

The MFM images of the magnetic domain structures of the surface of the film over microstrips show the complexity of their magnetic configuration (fig. 6). The random direction of the walls reveals the lack of an easy direction of magnetic anisotropy in the plane.

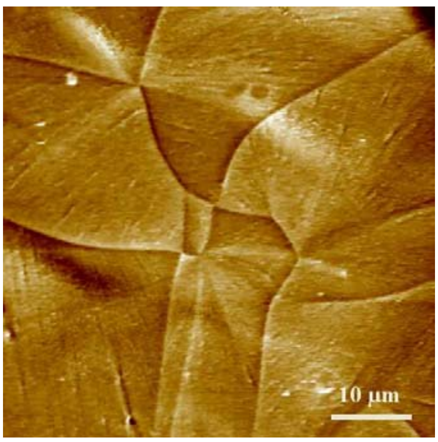


***Figure 6.*** *MFM image of a 8 µm-thick multilayer film covering a 8 µm-thick monolayer microstrip.*

## CONCLUSIONS

The magnetic properties of planar arrays of CoP monolayer microstrips and that of CoP multilayer films grown over these arrays have been studied using MOKE, VSM measurements and MFM. In the microstrip arrays it has been seen that the coercivity of the surface in the transversal direction is between 5 and 9 bigger than the coercivity in the longitudinal one. It has also been observed how the biasing of the array in a multilayer film grown over it leads to inverting the hysteresis in the surface of the latter.

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## 6.9 MEMS Magnetostatic Magnetic Sensor

In the last years, the interest in Micro-Electro Mechanical Systems (MEMS), also known as Microsystems Technology (MST), has widely increased. MEMS technology reduces the size, power consumption and price of the sensors and makes them more easily mass-produced. In aircrafts, for example, the mission price can be reduced considerably by the miniaturization of the sensors. In particular, magnetic sensors have not only civil applications but militar too, like UXO (unexploded ordnance) location, target detection, tracking and antitheft systems [1]. For all this applications smaller sensors can be more difficultly detected and they can be integrated in systems where space is a critical point. Recently, MEMS magnetometers based on different physical principles has been developed: Lorentz force [2,3], tunneling [4], torsion [5] and resonant structures [6,7]. In this work we propose a new MEMS based on magnetostatic effects.

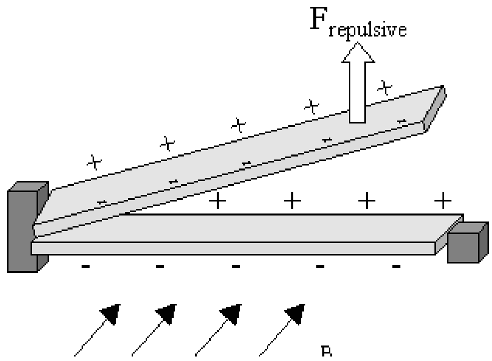


*Figure.1.* *Device set up.*

As it is well known, magnetic poles are induced in a body of finite size magnetized under the action of a magnetic field. These magnetic poles can attract or repeal other magnetized bodies. It is an old idea that is the base of the reed relays. The attraction or repulsion between two magnetized bodies depends on the relative position between them. So, the force between two plates placed one following to the other in the field direction is attractive. On the other hand, the force between two parallel plates placed, one over the other, is repulsive. The proposed magnetic sensor is based in this last set up employing two rectangular plates of the same dimensions as can be seen in figure 1. One of them is fixed whereas the other is placed over the former one and fixed only by one of its ends, in such a way that it behaves like a cantilever whose position is modified by the interaction between the magnetic poles induced by the

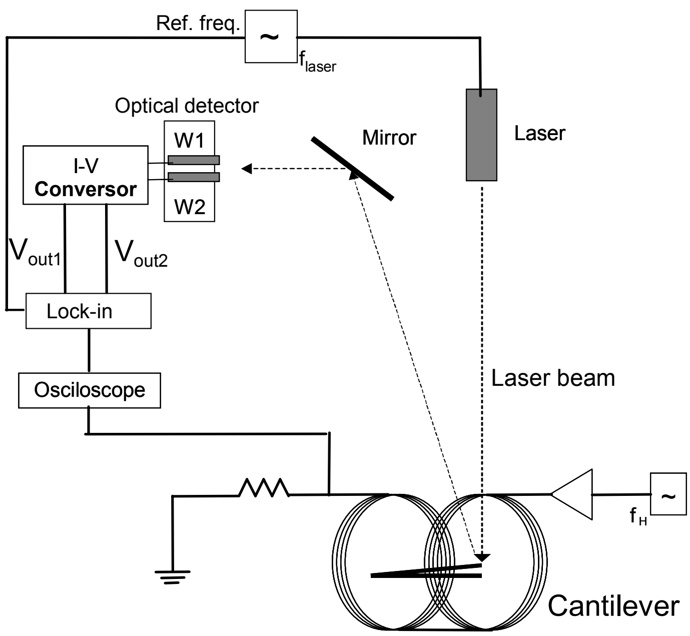


***Figure 2**. Optical Method Configuration*

applied magnetic field. So it will be possible to measure the applied field by measuring this displacement.

The applied magnetic field can be measured by illuminating the cantilever vertically with a laser beam. The deflection z is determined by measuring the angular change with an optical detector. A two windows optical detector is placed to determine the change of position of the laser beam.

The optical detector is formed by two detector windows (W1 and W2) placed vertically one above the other (Fig.2). When the cantilever bends, the laser, whose beam has a bigger diameter than the separation between the two detectors, changes the illumination degree in both of them. It causes a change of the electrical current produced. Two output voltages are obtained from the optical detector ($V_{out\ 1}$ and $V_{out\ 2}$ ) thanks to an I-V conversor (Fig.3). One is the inverse of the other. It is used to make a differential measurement and to eliminate the electrical noise (Fig. 2). The light noise has also been reduced by using an in phase detection: the laser power has been modulated chopping the laser light with a well known frequency ($f_{laser}$) and ($V_{out\ 1}$ - $V_{out\ 2}$) has been measured with a lock-in amplifier synchronized to this frequency (Ref. freq. in Fig. 2). The magnetic field to be measured is produced by two Helmholtz's coils. The sensor response was studied by plotting the magnetic field versus the output voltage signal of the lock-in ($V_{out\ lock-in}$) with an oscilloscope.

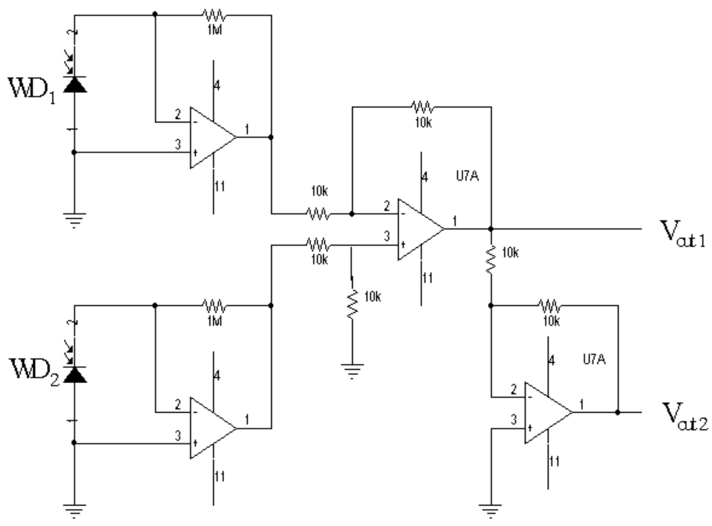


***Figure 3**. Detector electronics: I-V Conversor.*

All the structure to hold the laser, a mirror to orient the laser beam, the cantilever and the optical detector has been set up in the same structure made of methacrylate. To avoid mechanical vibrations, all that is suspended: they are not physically in contact with the Helmholtz coils used to produce the magnetic field. Three screws are used to orient the laser beam; the mirror can be horizontally spun; the optical detector is over a platform that can be moved vertically and horizontally with two micrometric screws, as shown in Figure 4.

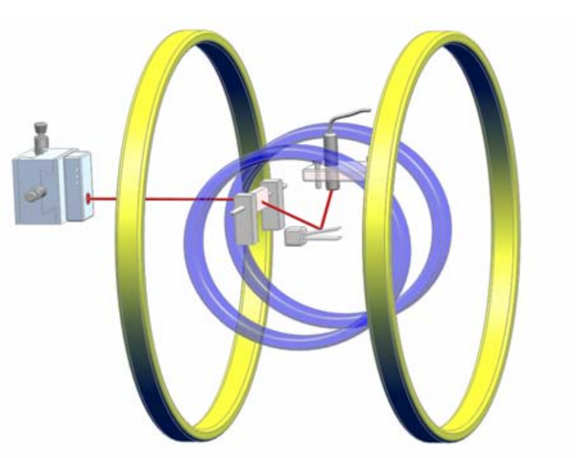

***Figure 4**. Optical method set-up*

## RESULTS AND CONCLUSIONS

A new magnetic sensor has been developed with high sensitivity and good linear response. Using a constant homogeneous magnetic field as off-set, a sensitivity of 10 V/T in the electrical and optical methods has been obtained for a cantilever of l = 2.22 cm, a= 1.2 mm and t = 30 μm (Fig.5-6). The sensitivity of the electrical method could be improved by using an in phase detection. Other way could be using an electronic set up as in [3].

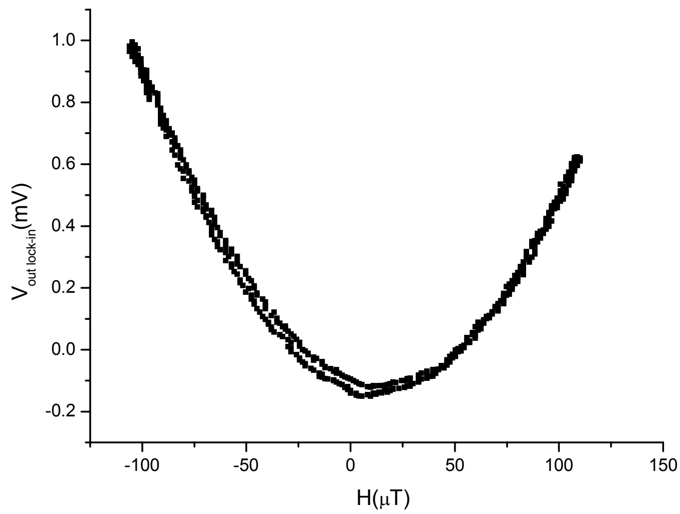


***Figure 5.*** *Optical Method Results.*
*l = 2.22 cm; a = 1.5 mm; t = 30 μm.*

MEMs magnetic sensors need a simple electronics and, in a first approximation, its accuracy and resolution increase by reducing its dimensions. However, there are specific noise sources in the case of MEMs due to the geometrical dimensions and mass [9]. In our case, as we are not employing the resonant properties of the cantilever, all this noise can be eliminated by integrating. In the case of the MEMs Magnetostatic Magnetic Sensor real problems can be the thermal expansion effects and the attractive stiction force [10] that can bend the cantilever. The mechanical properties of MEMS as thermal effects have been extensively studied and can be properly avoided [11]. The stiction force can be negligible by introducing a constant magnetic field as bias. Nowadays, MEMs and cantilevers can be made with a length in the order of 100 micra.

It must be underlined the absence of hysteresis when the electrostatic stiction force is avoided, although the sensor is still a prototype. The performance is similar to other sensors mentioned in [1].

Despite its actual dimensions, IC technologies (already used in sensors with similar geometry [*12, 13, 14*]) and the huge expand of new materials available for microsystems applications [*25*] ensure a successful and easy miniaturization of the developed sensor.

The described optical system is been used in measuring magnetostriction effects in thin magnetic films. Particularly, we are interested on the magnetostriction in amorphous cantilevers in and out of mechanical resonant frequencies.

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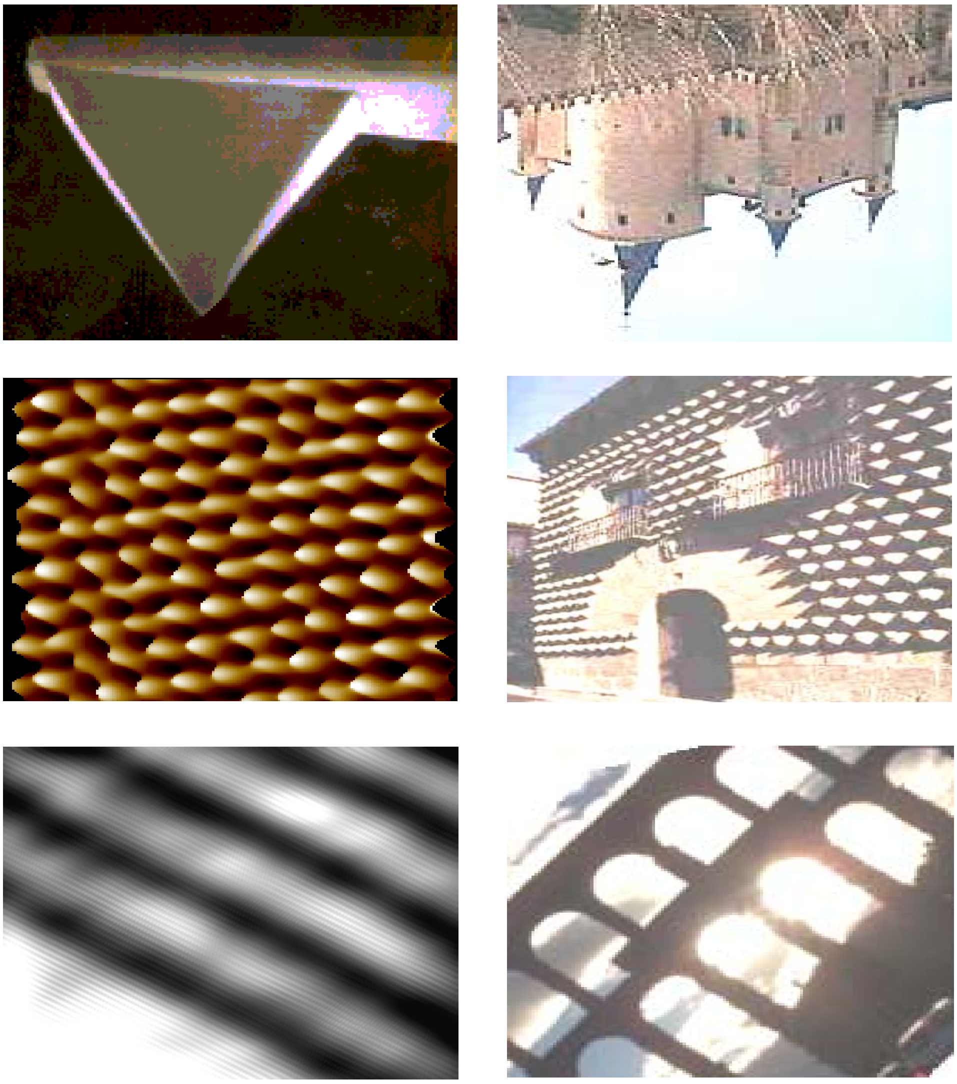
# 7. RESEARCH PROJECTS

heTech´03



12th European Workshop on

Heterostructure Technology

*12-15 October, 2003*

*San Rafael, Segovia, SPAIN*

## *7.1 Public National Funding*

***1. -*** ***"Detectores de infrarrojo de heteroestructuras cuánticas sobre GaAs"***
CICYT | TIC 2000-0380-C03 | 2000 - 2003
Principal Investigator (PI): Álvaro de Guzmán Fernández

***2. -*** ***"Desarrollo de un sistema multisensor para la determinación de carga de grandes baterías y de microsensores magnéticos mediante tecnología planar"***
CICYT | MAT 2000-0330-P4-03 | 2001 - 2003
PI: Pedro Sánchez Sánchez

***3. -*** ***"Emisores en 510 nm para Aplicaciones de Alta Temperatura"***
CICYT | TIC 2000-1887-CE | 2001 - 2004
PI: Enrique Calleja Pardo

***4. -*** ***"Sensores planares y materiales nanoestructurados para su integración en dispositivos magnéticos"***
MCYT | MAT 2001-3554-C02-01 | 2001 - 2004
PI: Claudio Aroca Hernández-Ros

***5. -*** ***"Tecnologías y Aplicaciones de Microsistemas Activos Inteligentes"***
MCYT | TIC 2001-3838-C03-01 | 2001 - 2004
ISOM PI: Elías Muñoz Merino

***6. -*** ***"Crecimiento Epitaxial por Haces Moleculares (MBE) de Aleaciones de InGaAsN. Aplicacion a Láseres en el rango 1.3 a 1.5 micras"***
MCYT | TIC 2001-3849 | 2001 - 2004
PI: Enrique Calleja Pardo

***7. -*** ***"Tecnología de Fabricación de Dispositivos de Alta Frecuencia/Alta Temperatura basados en Nitruros"***
MCYT | TIC 2001-2794 | 2001 - 2004
PI: Fernando Calle Gómez

***8. -*** ***"Fabricación y Evaluación de nuevos dispositivos de nitruro de Galio para transmisores de potencia de microondas"***
INDRA-MCYT (PROFIT) | FIT-02100-2002-720 | 2002 - 2003
PI: Elías Muñoz Merino

***9. -*** ***"Detectores de Infrarrojo Mediante Pozo Cuántico para Monitorización de Contaminantes en el Aire"***
CAM | 07M/0039/2001 | 2002 - 2003
PI: Álvaro de Guzmán Fernández

***10. -*** ***"Detectores de radiación infrarroja (4.2-4.7 µm) y ultravioleta-C (260-290 nm) para la rápida detección de incendios forestales"***
CAM | 07M-0110/2002 | 2002 - 2004
PI: Miguel Ángel Sánchez García

**11. -** ***"Heteroestructuras semiconductoras basadas en GalnNAs para optoelectronica en 1,5 micras"***

| | | |
|---|---|---|
| MCYT | TIC-2001-4950-E | 2002 - 2004 |
| PI: | Enrique Calleja Pardo | |

**12. -** ***"Sensores magnetométricos fluxgate miniaturizados. Aplicación en lectores de tarjetas inteligentes sin contactos"***

| | | |
|---|---|---|
| MCYT | TIC2002-04132-C02 | 2002 - 2005 |
| PI: | Pedro Sánchez Sánchez | |

**13. -** ***"Desarrollo de sensorización basada en fotodetectores GaN para monotorización de combustión"***

| | | |
|---|---|---|
| ORKLI-MCYT (PROFIT) | FIT-020100-2003-411 | 2003 - 2003 |
| PI: | Elías Muñoz Merino | |

**14. -** ***"Fabricación y evaluación de nuevos dispositivos de nitruro de galio para transistores de potencia de microondas"***

| | | |
|---|---|---|
| INDRA-MCYT (PROFIT) | FIT-020100-2002-720 | 2002 - 2002 |
| PI: | Elías Muñoz Merino | |

**15. -** ***"Fabricación y evaluación de nuevos dispositivos de nitruro de galio para transistores de potencia de microondas"***

| | | |
|---|---|---|
| INDRA-MCYT (PROFIT) | FIT-020100-2003-380 | 2003 - 2003 |
| PI: | Elías Muñoz Merino | |

**16. -** ***"Acción Especial, Servicios de la GIC"***

| | | |
|---|---|---|
| MCYT | TIC01-5402-E | 2003 - 2004 |
| PI: | Elías Muñoz Merino | |

## *7.2 Projects in collaboration with Industry and Public Institutions*

***1. -*** ***"Sensores de llama para gasodomésticos mediante detectores de ultravioleta de GaN"***
MONDRAGÓN CORPORACIÓN COOPERATIVA 2000 - 2003
PI: Elías Muñoz Merino

***2. -*** ***"Desarrollo de Sensores Magnéticos"***
CIDA 1003810048 2001-2002
PI: Pedro Sánchez Sánchez

***3. -*** ***"Asistencia técnica para el desarrollo de potencia HEMT de GaN para Microondas"***
CIDA 1053820100 2002-2003
PI: Elías Muñoz Merino

***4. -*** ***"Desarrollo de Transistores de GaN para Microondas"***
INDRA SISTEMAS, S. A 2002-2004
PI: Elías Muñoz Merino

***5. -*** ***"Desarrollo de detectores QWIP Tricolor"***
CIDA 10061018 2002-2003
PI: Álvaro de Guzmán Fernández

***6. -*** ***"Asistencia técnica para el desarrollo de sistemas de protección de vehículos"***
SIMAVE 2003 -2003
PI: Claudio Aroca Hernández-Ros

***7. -*** ***"Desarrollo de sensor UV"***
IKERLAN 2003-2004
PI: Elías Muñoz Merino

***8. -*** ***"Desarrollo de matrices de detectores QWIP tri-color"***
CIDA 1053830042 2003-2004
PI: Álvaro de Guzmán Fernández

***9. -*** ***"Desarrollo de Transistores de GaN de potencia para amplificadores de radiofrecuencia"***
CIDA 1053830118 2003 -2004
PI: Elías Muñoz Merino

## 7.3 International Funding

***1. - "Gallium nitride substrates and component"***

| | | |
|---|---|---|
| ESA CONTRACT | 13519/99/NL/MV:GaN | 1999-2003 |
| PI: | Elías Muñoz Merino | |

***2. - "Amber/Green emitters targeting high temperature applications" (AGETHA)***

| | | |
|---|---|---|
| ESPRIT | IST-1999-10292 | 2000 - 2003 |
| PI: | Enrique Calleja Pardo | |

***3. - "AlGaN Solar-Blind UV photodetectors fabricated on Si(111) substrate"***

| | | |
|---|---|---|
| ONERA-FRANCE | | 2001-2003 |
| PI: | Elías Muñoz Merino | |

***4. - "GaAs based multicolor IR Photodetectors for focal plane array applications" (QWIPS)***

| | | |
|---|---|---|
| ONR-NICOP | N00014 0010 366 | 2001- 2003 |
| PI: | Enrique Calleja Pardo | |

***5. - "GaInAsN-based semiconductor heterostructures for 1.5 micron Optoelectronics" (GINA 1.5)***

| | | |
|---|---|---|
| ESPRIT | IST-2000-23678 | 2001-2004 |
| PI: | Enrique Calleja Pardo | |

***6. - "P-type doping of GaN and AlGaN layers grown by MBE" (WIDEBANDGAP)***

| | | |
|---|---|---|
| ONR-NICOP | N00014-011-0828 | 2001- 2004 |
| PI: | Enrique Calleja Pardo | |

***7. - "New Generation of GaN-based sensor arrays for nano- and pico-fluidic systems for fast and reliable biomedical testing" (GANANO)***

| | | |
|---|---|---|
| STREP | NMP4-CT-2003-505641 | 2003-2006 |
| PI: | Elías Muñoz Merino | |

***8. - "A novel technology for ultra sensitive reliable integrated magnetic sensors: a new era in magnetic detection" (SENPIMAG)***

| | | |
|---|---|---|
| STREP | NMP2-CT-2003-505265 | 2003-2006 |
| PI: | Claudio Aroca Hernández-Ros | |

## *7.4 International Integrated Actions*

***1. -*** ***"Fabricación de Transistores HEMT de AlGaN/GaN sobre Si(111) para Microondas"***
Spain-Germany (Paul Drude Institut, Berlin)
HA-1999-2002 1999-2002
PI: Elías Muñoz Merino

***2. -*** ***"Detectores de Infrarrojo en Pozos Cuánticos de InGaAs/GaAs"***
Spain-UK (University of Sheffield)
HB1999-0028 2000-2002
PI: José Manuel García Tijero

***3. -*** ***"Estudio de las propiedades morfológicas de estructuras láser de pozo cuántico de InGaAsN crecidas por MBE"***
MCYT. Spain-Germany.
HA2002-0004 2003-2004
PI: Álvaro Guzmán Fernández

***4. -*** ***"Chemical and Biochemical Sensors based on group III-nitrides"***
Spain-Germany, with Walter Schottky Institüt
HA2002-0005 2003-2004
PI: Fernando Calle Gómez

# 8. PUBLICATIONS

**ISBLLED-2002**

Fourth International Symposium on
Blue Laser and Light Emitting Diodes

Córdoba (Spain), 11-15 March 2002

## 8.1 Papers in Scientific Journals and Books

*1.-* A.L. Álvarez, F. Calle, E. Monroy, J. L. Pau, M. A. Sánchez-García, E. Calleja, E. Muñoz
***"Interplay between Ga-N and Al-N sublattices in wurzite AlGaN alloys studied by Raman spectroscopy"***
Journal of Applied Physics 92, 223-226 (2002)

*2.-* F. Calle, F. B. Naranjo, S. Fernández, M. A. Sánchez-García, E. Calleja, E. Muñoz
***"Nitride RCLEDs grown by MBE for POF applications"***
Physica status solidi (a) 192, 27 (2002)

*3.-* F. Calle, T. Palacios, E. Monroy, J. Grajal, J. M. Tirado, A. Jiménez, R. Ranchal, E. Muñoz, M. Verdú, F. J. Sánchez, M. T. Montojo, Z. Bougrioua, I. Moerman
***"Fabrication and performance of AlGaN/GaN HEMTs"***
Proc. 4$^{th}$ Int Conf. Materials for Microelectronics and Nanoengineering, 25-28. ISBN: 1-86125-155-6. IOM Comm, Ltd (2002)

*4.-* E. Calleja, E. Muñoz, K. Ploog, editors
***"Proceedings of the Fourth International Symposium on Blue Laser and Light Emitting Diodes"***
Physica status solidi (a), 192,1-2 (2002)

*5.-* S. Cho, A. Majerfeld, J. J. Sánchez, E. Muñoz, J.M. G. Tijero, I. Izpura
***"Observation of the pyroelectric effect in strained Piezoelectric InGaAs/GaAs quantum-wells grown on (111)B GaAs substrates"***
Microelectronics Journal 33, 531-534 (2002)

*6.-* S. Fernández, F. B. Naranjo, F. Calle, E. Calleja, A. Trampert, K.H.Ploog
***"Growth and Characterization of High Quality Ten-priod AlGaN/GaN Bragg reflectors grown by MBE"***
Materials Science and Engineering B93, 31-34 (2002)

*7.-* S. Fernández, F. B. Naranjo, F. Calle, M.A. Sánchez-García, E. Calleja, P. Vennegues
***"High quality distributed Bragg reflectors for Resonant-cavity LED applications"***
Physica status solidi (a) 192, 389-393 (2002)

*8.-* T.Fleischmann, J.M.Ulloa, M.Moran, G.J.Rees, J.Woodhead and M.Hopkinson,
***"Characterisation of strained (111)B InGaAs/GaAs quantum well lasers with intracavity optical modulator"***
Microelectronics Journal 33, 547-552 (2002)

*9.-* E.R. Glaser, S.C. Binari, G.C. Braga, W.E. Carlos, J. A. Freitas, R.L. Henry, D. D. Koleske, W.J. Moore, B.V. Shanabrook, A. E. Wickenden, M.W. Bayerl, M.S. Brandt, H. Obloh, P.Kodozoy, S.P. Denbaars, U.K, Mishra, S. Nakamura, E. Haus, J.S. Speck, J.E. Van Nostrand, M.A Sánchez, E. Calleja, A.J. Ptak, T.H. Myers, R. J. Molnar
***"Characterization of Nitrides by Electron Paramagnetic Resonance (EPR) and Optically Detected Magnetic Resonance (ODMR)"***
Materials Science & Engineering B93, 39 (2002)

*10.-* A. Guzmán, E. Tournié, M.-A Pinault.
***"Mechanism affecting the photoluminescence spectra of GaInNas after post-growth annealing"***
Appl. Phys. Lett. 80 (22), 4148-4152 (2002)

***11.-*** J. Hernando, J.M.G. Tijero, J.L. Sánchez- Rojas
***"Temperature control in InGaAs-based quantum well structures grown by molecular beam epitaxy on GaAs(100) and GaAs(111)B substrates"***
Journal of Crystal Growth 246,1-8 (2002)

***12.-*** A. Hierro, A. R. Arehart, B. Heying, M. Hansen, U.K. Misrhra, S. P. Denbaars, J.S.Speck, S.A. Ringel
***"Impact of Ga/N flux ratio on trap states in n-GaN grown by plasma-assisted molecular beam epitaxy"***
Appl. Phys. Lett. A, 80, 805-807 (2002)

***13.-*** R. J. Jiménez Riobóo, E. Rodríguez-Cañas, M. Vila, C. Prieto, F. Calle, T. Palacios, M.A. Sánchez-García, F. Omnés, O. Ambacher, B. Assouar, O. Elmazria
***"Hypersonic characterization of sound propagation velocity in AlGaN thin films"***
Journal Applied Physics 92, 6868-6874 (2002)

***14.-*** A. Jiménez, D. Buttari, D. Jena, R. Coffie, S. Heikman, N.Q. Zhang, L. Shen, E. Calleja, E. Muñoz, J. Speck, U.K. Mishra
***"Effect of p-Doped Overlayer Thickness on RF-Dispersion in GaN Junction Field Effect Transistors"***
IEEE Electronic Device Letters 23 (6), 306-309 (2002)

***15.-*** A. Jiménez, E. Calleja, E. Muñoz, M. Varela, C. Ballesteros. U.Jahn, K. Ploog, F. Omnés, P. Gibart
***"Correlation between transport, optical and structural properties in AlGaN/GaN heterostructures"***
Materials Science & Engineering B93, 64 (2002)

***16.-*** A. Link, T. Graf, O. Ambacher, A. Jiménez, E. Calleja, Y. Smorchkova, J. Speck, U. Mishra, M. Stutzmann
***"Transport Properties of 2DEGs in AlGaN/GaN Heterostructures: Spin Splitting and Occupation of Higher Subbands"***
Physica Status Solidi (a), Phys. Stat. Sol. (b) 234, nº3, 805-809 (2002)

***17.-*** E. López Cabarcos, A. F. Braña, B. Frick, F. Batallán
***"Molecular dynamics and thermal hysteresis loops of the vinilydene fluoride – trifluoroethylene ferroelectric copolymer"***
Phys Rev. B 65, 104110 (2002)

***18.-*** E. López Cabarcos, A. F. Braña, B. Frick, F. Batallán
***"Corrlation between Molecular Dynamics and Thermal Hysteresis in the 60/40 Vinylidene Fluorideand trifluoroethylene Ferroelectric Copolymer"***
Physica-A, 314. 714-21 (2002)

***19.-*** E. Luna, A. Guzmán, J.L. Sánchez-Rojas, J. Miguel-Sánchez, A. Guzmán, E. Muñoz
***"GaAs-Based Modulation-Doped Quantum-Well Infrared Photodetectors for Single-and Two-Color Detection in 3-5 µm"***
IEEE Journal of Selected Topics in Quantum electronics, 8 (5), 992-997 (2002)

***20.-*** M. Maicas, M. A. Rivero, E. López, C. Aroca, M.C. Sánchez, P. Sánchez
***"Micromagnetic structures in square magnetic dots"***
J. Mag. Mag. Mat., 242-245, 1024-1025 (2002)

**21.-** M. Maicas, M. Rodríguez, E. López, M.C. Sánchez, C. Aroca, P. Sánchez
***"Magnetic switching fields in square monolayer and bilayer nanodots"***
Comp. Mat. Sci. 25, 525-530 (2002)

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## *8.2 Conferences and Meetings*

***1.-*** Z. Bougrioua, I. Moerman, L. Nistor, M. Leroux, E. Monroy, T. Palacios, F. Calle
***"Engineering of an Insulating Buffer and Use of AlN Interlayers: two optimisations for AlGaN-GaN HEMT-like structures"***
Expert Evaluation and Control of Compund Semiconductor Materials and Tecnologies, EXMATEC 2002 Budapest (Hungary), 2002

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***"Nitride RCLEDs grown by MBE for POF applications"***
4$^{th}$ Int. Symp. Blue Laser and Light Emitting Diodes
Córdoba (Spain), 2002

***3.-*** F. Calle, T. Palacios, E. Monroy, J. Grajal, J.M. Tirado, A. Jiménez, R. Ranchal, E. Muñoz, M. Verdú, F. J. Sánchez, M. T. Montojo, Z. Bougrioua, I. Moerman
***"Fabrication and characterization of AlGaN/GaN HEMTs"***
Proceeding 4th International Conference on Materials for Microelectronics
Espoo (Finland), 2002

***4.-*** E. Calleja
***"Transport Properties of 2DEGs in AlGaN/GaN Heterostructures: Spin Splitting and Occupation of Higher Subbands"***
Int. Conf. on Nitrides (IWN-2002)
Aachen (Germany), 2002

***5.-*** E. Calleja
***"Hetero- and Homoepitaxial Growth of III-Nitrides by MBE. P-Doping, Nanostructures and Devices"***
International Workshop on Nitrides (IWN-2002)
Aachen (Germany), 2002

***6.-*** E. Calleja
***"Wide BandGap Semiconductors at ISOM"***
Workshop on Micro and Nano Technologies
Barcelona (Spain), 2002

***7.-*** E. Calleja
***"AlGaN/GaN/AlGaN Nanocavities in III-Nitride Nanocolumns"***
4$^{th}$ Workshop on Physics of Light-Matter Coupling in Advanced Heterostructures
Sicilia (Italy), 2002

***8.-*** S. Fernández, F. B. Naranjo, F. Calle, M. A. Sánchez-García, E. Calleja, P. Vennegues
***"High quality distributed Bragg reflectors for Resonant-cavity LED applications"***
4$^{th}$ Int.Symp. Blue Laser and Light Emitting Diodes
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**10.-** J-F. Hochedez, U. Schühle, J. L. Pau, O. Hainaut, E. Pace, J. A. Álvarez, T. Appourchaux, D. F.Auret, A. Elsky. P.Bergonzo, M.C. Castex, A. Deneuville, P.Dhez, B. Fleck, K. Haenen, M. Idir, J.P. Kleider. E. Lefeuvre, P. Lemaire, E. Monroy, P. Muret, E.Muñoz, M. Nesladek, F. Omnes, A. Peacock, C. Van Hoof
***"New UV detectors for solar observations"***
SPIE Photonics West 2002
San José (USA), 2002

**11.-** E. Luna, A. Guzmán, A. Trampert, J.L Sánchez-Rojas, E. Calleja
***"On the growth conditions of 3-µm well doped AlGaAs/AlAs/GaAs infrared detectors and its relation to the photovoltaic effect studied by Transmission Electron Microscopy"***
QWIP 2002 Workshop
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***"Modulation doping in 3-5 µm GaAs/AlAs/AlGaAs double barrier quantum well infrared photodetectors: an alternative to achieve high photovoltaic performance at high temperature detection"***
QWIP 2002 Workshop
Torino (Italy), 2002

**13.-** M.D Michelena, E. López, C. Aroca, P. Sánchez, M. C. Sánchez
***"PVDF-Metglas magnetic sensor"***
4$^{th}$ European Magnetic Sensor and Actuator Conference (EMSA 2002)
Athens (Greece), 2002

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***"Activities on Nitride Semiconductors at ISOM-UPM"***
Joint Spanish-German-Japanese Seminar on Optoelectronic Materials and Devices
Córdoba (Spain), 2002

**15.-** F.B Naranjo, S. Fernández, F. Calle, M.A. Sánchez-García, E. Calleja
***"From UV to green InGaN-based Standard and Resonant-cavity LEDs grown by MBE"***
4$^{th}$ Int. Symp. Blue Laser and Light Emitting Diodes
Córdoba (Spain), 2002

**16.-** T. Palacios, E. Monroy, F. Calle, F. Omnes
***"Technology and Performance of Submicron Metal-semiconductor-metal GaN Ultraviolet Detectors"***
60$^{th}$ Annual Device Research Conference
Sta. Bárbara (USA), 2002

**17.-** T. Palacios, F. Calle, E. Monroy, F. Omnes
***"Novel approaches for submicron metal-semiconductor-metal GaN UV photodetectors"***
Int. Workshop on Nitrides
Aachen (Germany), 2002

**18.-** T. Palacios, F. Calle, E. Monroy, J. Grajal, M. Eickhoff, O. Ambacher, R. Jiménez, C. Prieto
***"AlGaN/sapphire epilayers for Acoustic Wave Devices"***
2002 Electronics Materials Conference
Sta. Bárbara (USA), 2002

***19.-*** T. Palacios, F. Calle, J. Grajal, E. Monroy, M. Eickhoff, O. Ambacher, F. Omnes
***"High Frequency SAW Devices on AlGaN: Fabrication, Characterization and Integration with Optoelectronics"***
IEEE Int. Symp. on Ultrasonics
Munich (Germany), 2002

***20.-*** J.L. Pau, E. Muñoz, M. A. Sánchez-García, E. Calleja
***"Visible and solar blind AlGaN metal conductor metal photodetectors grown on Si (111) substrates"***
4th Int. Symp. Blue Laser and Light Emitting Diodes
Córdoba (Spain), 2002

***21.-*** J.L. Pau, E. Muñoz, M. A. Sánchez-García, E. Calleja
***"Solar Blind AlGaN based UV photodetectors grown on Si(111) substrates"***
SPIE Photonics West 2002
San José (USA), 2002

***22.-*** J.L. Pau, F. B. Naranjo, A. Jiménez, M. A. Sánchez-García, E. Calleja, E. Muñoz
***"AlGaN ultraviolet photodetectors grown by molecular beam epitaxy on Si(111)"***
SPIE Photonics West 2002
San José (USA), 2002

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***"Influencia de las condiciones de crecimiento en las propiedades magnéticas de las aleaciones de CoNiFe"***
II Reunión Nacional de G.E.F.E.S. de la R.S.E.F
Calella-Barcelona (Spain), 2002

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***"Magnetic domain structures in CoNiFe Thin Films and lines"***
Materials Research Soc. Symp, Proceedings
Boston (USA), 2002

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***"Influencia de la anisotropía en la magnetorresistencia de tricapas de permalloy/cobre/permalloy"***
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***"Temperature effect on spin-flop displacement of permalloy/gadolinium/permalloy thin films"***
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***27.-*** S. A. Ringel, A. Hierro, A. R. Arehart, B. Heying, B. Moran, M. Hansen, U. K. Mishra, S.P. Denbaars, J. S. Speck
***"A comparison of traps present in MBE and MOCVD n-GaN"***
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Córdoba (Spain), 2002

**28.-** J. Ristic, M. A. Sánchez-García, E. Calleja, J. Sánchez-Páramo, J. M. Calleja, U. Jahn, K. H Ploog;
***"AlGaN Nano-columns grown by Molecular Beam Epitaxy: Optical and structural characterization"***
4th International Symposium on Blue Lasers and Light Emitting Diodes (ISBLLED2002)
Córdoba (Spain), 2002

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Hawai (USA), 2002

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***"Magnetization processes in square bilayer dots"***
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***"Luminescence and morphological properties of GaN layers grown on SiC/Si(111) substrates"***
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Córdoba (Spain), 2002

**33.-** J.M. Ulloa, J.L Sánchez-Rojas, A. Hierro, J.M.G. Tijero
***"Effect of Nitrogen on the Band-Structure and Material Gain of In(x)Ga(1-x)As(1-y)N(y)/GaAs Quantum Wells"***
International Conference on Numerical Simulation of Semiconductor Optoelectronic Devices
Zürich (Switzerland), 2002

**34.-** C. Aroca
***"Magnetic sensors"***
12 th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

**35.-** A.F. Braña, A. Jiménez, E. Muñoz, E. Calleja
***"Scattering mechanism in AlGaN/GaN heterostructures"***
5ª Conferencia de Dispositivos Electrónicos CDE-2003
Barcelona (Spain), 2003

**36.-** F. Calle, T. Palacios, J. Grajal, J. Pedrós
***"UV detectors modulated by surface accoustic waves"***
OPTOEL'03, 3ª Reunión Española de Optoelectrónica
Madrid (Spain), 2003

***37.-*** E. Calleja, J. Ristic
***"Self-assembled Growth of GaN/AlGaN Nanostructures by MBE"***
Trends in Nanotecnology. TNT´2003
Salamanca (Spain), 2003

***38.-*** E. Calleja, J. Ristic
***"Self-assembled Growth of GaN/AlGaN Nanostructures by MBE"***
4$^{th}$ Int. Workshop on Physics of Light-Matter Coupling in Nanostructures
Acireale, Sicily (Italy), 2003

***39.-*** E. Calleja, J. Ristic, M.A. Sánchez-Garcia, A. Trampert, K.H. Ploog, J. Sánchez-Páramo, J. M. Calleja
***"Growth of Nitride Nanostructures"***
12$^{th}$ European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***40.-*** D. Ciudad, C. Aroca, M.C. Sánchez, E. López, P. Sánchez
***"Sensor Magnetostático para la medida de campos magnéticos"***
XXIX Reunión Bienal de la R.S.E.F
Madrid (Spain), 2003

***41.-*** D. Ciudad, C. Aroca, M.C. Sánchez, E. López, P.Sánchez
***"Bent Beam Magnetic Sensor"***
12$^{th}$ European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***42.-*** D. Ciudad, C. Aroca, M.C. Sánchez, E. López, P.Sánchez
***"Magnetostatic magnetic sensor"***
Eurosensors XVII (European Conference on Solid-State Transducers)
Guimaraes (Portugal), 2003

***43.-*** O. de Abril, P. López-Alcarz, M. C. Sánchez, C. Aroca, E. López, P. Sánchez
***"Producción de muestras masivas ferromagnéticas de cobalto mediante electrodeposición"***
XXIX Reunión Bienal de la R.S.E.F
Madrid (Spain), 2003

***44.-*** A. del Prado, E. San Andrés, I. Mártil, G. González-Díaz, K. Kliefoth, W. Füssel
***"Annealing Effects on the Interface and Insulator Properties of Al/SiOxNyHz/Si Devices"***
12$^{th}$ European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***45.-*** J.L. García-Pomar, L. Pérez, Ó de Abril, C. Aroca, P. Sánchez, E. López, M.C. Sánchez
***"Reduction of eddy current losses in sintered Permalloy for application in transformers"***
16$^{th}$ Soft Magnetic Materials Conference (SMM16)
Düsseldorf (Germany), 2003

***46.-*** M. González-Guerrero, L. Pérez, C. Aroca, M.C. Sánchez, E. Pérez, P. Sánchez
***"Excitación de un fluxgate planar mediante ferritas blandas"***
XXIX Reunión Bienal de la R.S.E.F
Madrid (Spain), 2003

**47.-** M. González-Guerrero, L. Pérez, C.Aroca, M. C. Sánchez, E. López, P. Sánchez
***"Planar fluxgate and soft ferrites"***
12 th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

**48.-** M. González-Guerrero, L. Pérez, C.Aroca, M. C. Sánchez, E. López, P. Sánchez
***"Hybrid Ferrite-Amorphous Planar Fluxgate"***
International Conference on Magnetism, Proceedings
Rome (Italy), 2003

**49.-** M. Gutiérrez, M. Hopkinson, H.Y.Liu, J. Miguel-Sanchez, A. Guzmán, M. Herrera, D. González, R. García
***"Comparision between growth mechanisms in dilute nitrides growns on (111)B and (001) GaAs Substrates"***
Epitaxial Semiconductors on Patterned Substrates and Novel Index Surgaces (ESPS-NIS)
Stuttgart (Germany), 2003

**50.-** A. Hierro, J. M. Ulloa, J.M. Chauveau, A. Trampert, M.A. Pinault, E. Tournié, A. Guzmán, J.L Sánchez-Rojas, E. Calleja
***"Effect of interface roughening on the luminescence properties of GaInNAs/GaAs quantum well"***
9 th International Conference on the Formation of Semiconductor Interfaces (ICFSI-9)
Madrid (Spain), 2003

**51.-** A. Hierro, J.M Ulloa, A. Trampert, J.M Chauveau, M.A. Pinault, E. Tournié, A.Guzmán
***"Role of growth mode on the structural reorganization of InGaAsN/GaAs QWs upon rapid-thermal-annealing"***
12 th Euro-MBE Workshop
Bad Hofgastein (Austria), 2003

**52.-** A. Jiménez, J.M Tirado, Z. Bougrioua, A.F. Braña, J. Grajal, P.P.Cubilla, E.Muñoz, E. Calleja, M. Verdú, M.T. Montojo. I. Moerman
***"Improved HEMT devices from AlGaN/GaN heterojunctions using AlN interlayers"***
WOCSDICE (27th Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe)
Fürigen (Switzerland), 2003

**53.-** A. Jiménez, P.P. Cubilla, A.F. Braña, Y.J. Fernández , E. Calleja, E. Muñoz
***"Critical steps in AlGaN/GaN HEMTs processing: ohmic contacts"***
12 th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

**54.-** A.Jiménez, Z. Bougrioua, E. Muñoz, E. Calleja
***"Growth of High Quality AlGaN/GaN HEMTs by PA-MBE on MOCVD GaN Templates"***
WOCSDICE (27th Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe
Fürigen (Switzerland), 2003

**55.-** E. Luna, M. Hopkinson, A. Guzmán, J.M Ulloa, E. Muñoz
***"Double barrier AlGaAs/AlAs/(In) GaAsN quantum well infrared"***
7 th International Conference on Intersubband Transition in Quantum Wells ITQW´03
Evolène (Switzerland), 2003

**56.-** E. Luna, M. Hopkinson, A. Guzmán, J.M Ulloa, E. Muñoz, E. Calleja
***"Study of MBE grown N-dilute alloys for their potential application in double barrier quantum well infrared photodetectors operating below 3.5 µm"***
12 th Euro-MBE Workshop
Bad Hofgastein (Austria), 2003

**57.-** M.D Michelena, L. Pérez, C. Aroca, E. López, M.C. Sánchez, P. Sánchez
***"Magnetostrictive-bimorph sensor based on electrodeposited"***
17 th European Conference on Solid State Transducers (Eurosensors)
Guimaraes (Portugal), 2003

**58.-** J. Miguel-Sánchez, A. Guzmán, J. Hernando, A. Hierro, E. Muñoz
***"Growth of InGaAsN single quantum well p-I-n structures on GaAs (111)B substrates for laser applications"***
12 th Euro-MBE Workshop
Bad Hofgastein (Austria), 2003

**59.-** J. Miguel-Sánchez, A. Guzmán, J.M. Ulloa, A. Hierro, E. Muñoz
***"Influence of surface misorientation on N incorporation in InGaAsN/GaAs quantum wells grown on (111)B GaAs"***
Epitaxial Semiconductors on Patterned Substrates and Novel Index Surgaces (ESPS-NIS)
Stuttgart (Germany), 2003

**60.-** E. Muñoz
***"InGaN/AlGaN-based UV photodetectors"***
Technische Universiteit Eindhoven, 5600 MB
Eindhoven (The Netherlands), 2003

**61.-** E. Muñoz, J.L Pau, C.Rivera
***"Nitride Photodetectors in UV biological effects studies"***
NATO ARW on UV solid-state light emitters and detectors.
Vilnius (Lithuania), 2003

**62.-** J.A. Nieto, A. F. Braña, A. Jiménez, P.P. Cubilla, Y.J. Fernández de Bobadilla, J. Grajal, M.T Montojo, M. Verdú, E. Muñoz
***"AlGaN/GaN High elector mobility transistors"***
Microelectronics Wide Band Gap Workshop, WEAG/CEPA 2
Gothenburg (Sweden), 2003

**63.-** J.L. Pau, O. Hainout, C. Rivera, E. Muñoz, J.F. Hochedez, F.Omnès, U. Schüle, P. Lemaire
***"Fabrication and characterization of AlGaN photodetectors for applications in the UV/XUV ranges"***
Proceedings CDE 2003
Calella de la Costa (Spain), 2003

**64.-** J. Pedrós, F. Calle, J. Grajal, T. Palacios, A. Jiménez, F. Omnès, Z. Bougrioua
***"Saw devices on 2DEG AlGaN/GaN heterostructures"***
12 th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***65.-*** L. Pérez, N. F. Martínez, C. Aroca, P. Sánchez, E. López, M. C. Sánchez
***"Sensor magnético planar de tipo fluxgate con núcleo electrodepositado fabricado con tecnología de circuito impreso"***
XXIX Reunión Bienal de la R.S.E.F
Madrid (Spain), 2003

***66.-*** R. Ranchal, E. López, M.C. Sánchez, C. Aroca, P.Sánchez
***"Electrical characterization of Py/Gd/Py trilayers in the CIP configuration"***
Trends in Nanotecnology. TNT´2003
Salamanca (Spain), 2003

***67.-*** R. Ranchal, E. López, M.C. Sánchez, C. Aroca, P.Sánchez
***"Magnetic and Electrical Characterization of Py/Gd/Py Trilayers"***
12 th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***68.-*** R. Ranchal, E.U. López, E. López, M.C. Sánchez, C. Aroca, P. Sánchez
***"Efecto del espesor del gadolinio en el comportamiento magnético de tricapas de Permalloy/Gadolinio/Permalloy"***
XXIX Reunión Bienal de la R.S.E.F
Madrid (Spain), 2003

***69.-*** J. Ristic, M.A. Sánchez-García, E. Calleja, A. Trampert, K.H. Ploog. J. Sánchez-Páramo, J.M. Calleja;
***"Self-organized molecular beam epitaxial growth of AlGaN/GaN nanostructrues for Optoelectronic applications"***
Future Trends in Microelectronics: The Nano, the Giga, the Ultra, and the Bio
Córcega (France), 2003

***70.-*** J. Ristic, M.A. Sánchez-García, E. Calleja, A. Trampert, K.H. Ploog. J. Sánchez-Páramo, J.M. Calleja
***"Molecular beam epitaxy growth of self-organized of GaN based nanostructures for optoelectronic applications"***
9th International Conference on the Formation of Semiconductor Interfaces (ICFSI-9)
Madrid (Spain), 2003

***71.-*** J. Ristic, M.A. Sánchez-García, J.M. Ulloa, E. Calleja, U. Jahn, A. Trampert, K.H.Ploog
***"GaN Quantum Discs Embedded in AlGaN Nanocolumns: Quantum Confinement Effects"***
12 th Euro-MBE Workshop
Bad Hofgastein (Austria), 2003

***72.-*** C. Rivera, J.L. Pau, E. Muñoz, F.B. Naranjo, E. Calleja
***"InGaN/(Al,Ga)N multiple-quantum-well-based photodetectors"***
12th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***73.-*** C. Rivera, J.L. Pau, O. Hainout, E. Muñoz
***"On the photoresponse of (Al,Ga)N-based UV detectors at high energy photons"***
WOCSDICE (27th Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe)
Fürigen (Switzerland), 2003

**74.-** M.A. Rivero, M. Maicas, E. López, M. C. Sánchez, C. Aroca, P. Sánchez
***"Estructuras magnéticas de dots cuadrados de monocapas y bicapas ferromagnéticas"***
XXIX Reunión Bienal de la R.S.E.F
Madrid (Spain), 2003

**75.-** M.A. Rivero, M. Maicas, M. D. Michelena, E. López, M. C. Sánchez, C. Aroca, P. Sánchez
***"Study of closed flux micromagnetic trilayers"***
16$^{th}$ Soft Magnetic Materials Conference, Proceedings
Dusseldorf (Germany), 2003

**76.-** E. San Andrés, A. Del Prado, I. Mártil, G. González-Díaz
***"Si surface optimization in the fabrication of SiNy/Si based MIS devices"***
12$^{th}$ Euro-MBE Workshop
Bad Hofgastein (Austria), 2003

**77.-** J.M. Tirado, A. Jiménez, A.F. Braña, E. Muñoz, M. Verdú, M.T. Montojo, Z.Bougrioua, I. Moerman, R. Ranchal, P.P. Cubilla, Y.J. Fernández de Bobadilla, J. Grajal
***"Fabrication and Characterization of AlGaN/GaN heterostructures"***
5ª Conferencia de Dispositivos Electrónicos CDE-2003
Barcelona (Spain), 2003

**78.-** A. Trampert, J. Ristic, U. Jahn, E. Calleja, K.H. Ploog
***"TEM study of (Ga,AI)N nanocolumns and embedded GaN nanodiscs"***
13$^{th}$ International Conference on Microscopy in Semiconductor Materials (MSM 2003)
Cambridge (UK), 2003

**79.-** J.M. Ulloa, A. Hierro, J.Miguel-Sánchez, A. Guzmán, M.A. Pinault, E. Tournié, E. Calleja
***"Dominant Recombination Processes in GaInNAs/GaAs QW Light Emitting Diodes"***
Materials Research Soc. Symp, Fall Meeting
Boston (USA), 2003

**80.-** J.M. Ulloa, A. Hierro, J.Miguel-Sánchez, A. Guzmán, M.A. Pinault, E. Tournié, J.L Sánchez-Rojas, E. Calleja, E. Muñoz
***"GaInN/GaAs quantum well devices for infrared emission applications"***
12$^{th}$ European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

## *8.3 Invited Talks*

***1.-*** F. Calle Gómez
***"Nitride RCLEDs grown by MBE for POF applications"***
4th Int.Symp. Blue Laser and Light Emitting Diodes
Córdoba (Spain), 2002

***2.-*** E. Calleja Pardo
***"MBE Growth of III-Nitrides"***
UNIPRESS Research Center. Polish Academy of Sciences
Warsaw (Poland), 2002

***3.-*** E. Muñoz Merino
***"Activities on Nitride Semiconductors at ISOM-UPM"***
Joint Spanish-German-Japanese Seminar on Optoelectronic Material and Devices
Córdoba (Spain), 2002

***4.-*** F Calle Gómez
***"Actividades de Investigación y Desarrollo Tecnológico en el Instituto de Sistemas Optoelectrónicos y Microtecnología"***
1ª Jornada de Investigación y Desarrollo Tecnológico de la ETSI Telecomunicación
Madrid (Spain), 2003

***5.-*** E Calleja Pardo
***"Self-assembled Growth of GaN/AlGaN Nanostructures by MBE"***
4th Int. Workshop on Physics of Light-Matter Coupling in Nanostructures
Sicilia (Italy), 2003

***6.-*** E Calleja Pardo
***"Self-assembled Growth of GaN/AlGaN Nanostructures by MBE"***
Trends in Nanotecnology. TNT´2003
Salamanca (Spain), 2003

***7.-*** E Calleja Pardo
***"Growth of Nitride Nanostructures"***
12th European Workshop on Heterostructure Technology
San Rafael-Segovia (Spain), 2003

***8.-*** E Muñoz Merino
***"InGaN/AlGaN-based UV photodetectors"***
Technische Universiteit Eindhoven, 5600 MB
Eindhoven (the Netherlands), 2003

***9.-*** E Muñoz Merino
***"Nitride Photodetectors in UV biological effects studies"***
NATO ARW on UV solid-state light emitters and detectors
Vilnius (Lithuania), 2003

## 8.4 Ph.D. Thesis

Title: ***"Crecimiento y caracterización de nitruros del grupo III sobre Si(111) por epitaxia de haces moleculares"***
Author: Miguel Ángel Sánchez García
Director: Enrique Calleja Pardo
University: Politécnica de Madrid, E.T.S. Ing. de Telecomunicación, 2000
Grade: Sobresaliente, "Cum Laude"
**Extraordinary prize of doctorate by Universidad Politécnica de Madrid (2002)**

Title: ***"Fabricación de diodos electroluminiscentes de cavidad resonante por epitaxia de haces moleculares"***
Author: Fernando Naranjo Vega
Director: Enrique Calleja Pardo
University: Politécnica de Madrid, E.T.S. Ing. de Telecomunicación, 2003
Grade: Sobresaliente, "Cum Laude"

Title: ***"Diseño, crecimiento y caracterización de heteroestructuras AlGaN/GaN para transistores de alta frecuencia/potencia"***
Author: Ana Jiménez Martín
Director: Enrique Calleja Pardo
University: Politécnica de Madrid, E.T.S. Ing. de Telecomunicación, 2003
Grade: Sobresaliente, "Cum Laude"

Title: ***"Fabricación, caracterización y aplicaciones de detectores de UV basados en AlGaN"***
Author: José Luis Pau Vizcaíno
Directors: Elías Muñoz Merino, Enrique Calleja Pardo
University: Politécnica de Madrid, E.T.S. Ing. De Telecomunicación, 2003
Grade: Sobresaliente, "Cum Laude"

## 8.5 B.Sc. Thesis

Title: ***Estudio de la absorción óptica de contaminantes***
Author: Jacobo Crespo Medina
Director: Fernando Calle Gómez
Grade: Matrícula de Honor, 10 p.
Date: Febraury 28, 2002

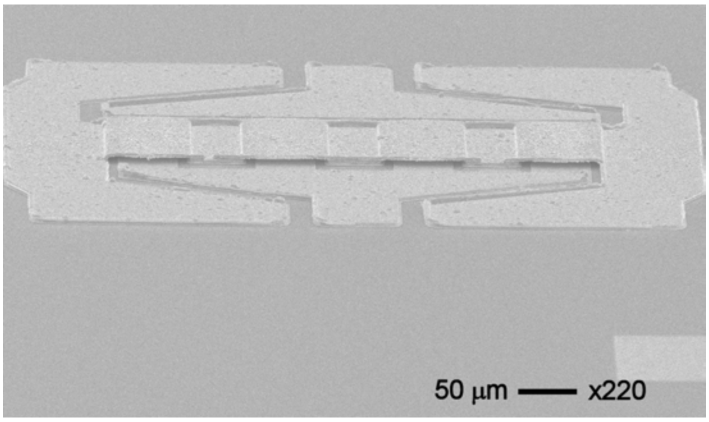
Title**: *Medida de la responsividad de detectores de infrarrojo de pozos cuánticos***
Author: Carlos Rivera de Lucas
Director: Álvaro Guzmán Fernández
Grade: Matrícula de Honor, 10 p.
Date: September 27, 2002

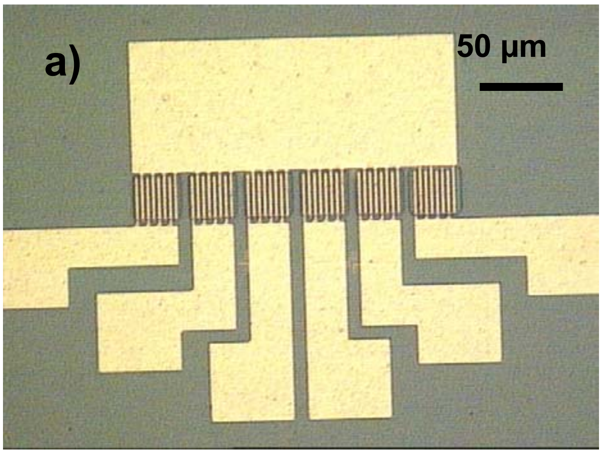
Title**:** ***Diseño y desarrollo de un sistema de detección de llama para gasodomésticos basado en detectores de ultravioleta de AlGaN***
Author: Marcos Redondo Cabanillas
Director: Elías Muñoz Merino
Grade: Matrícula de Honor, 10 p.
Date: October 4, 2002

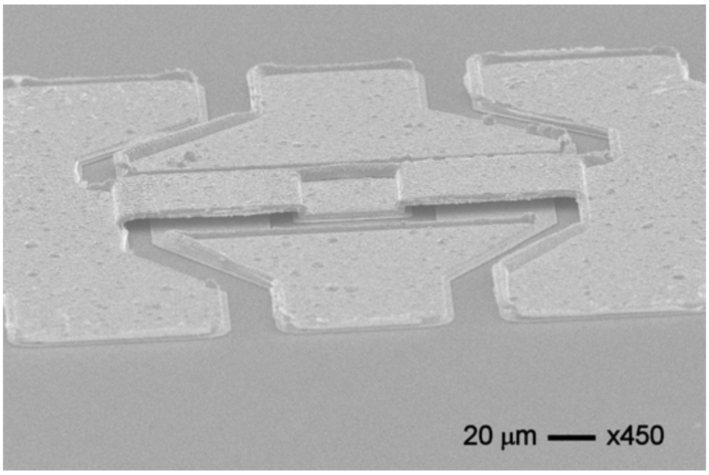
Title: ***Sistema de control de un biosensor basado en micropalanca de silicio***
Author: Miguel Fadón Perlines
Director: José Ignacio Izpura
Grade: Matrícula de Honor, 10 p.
Date: December 16, 2002

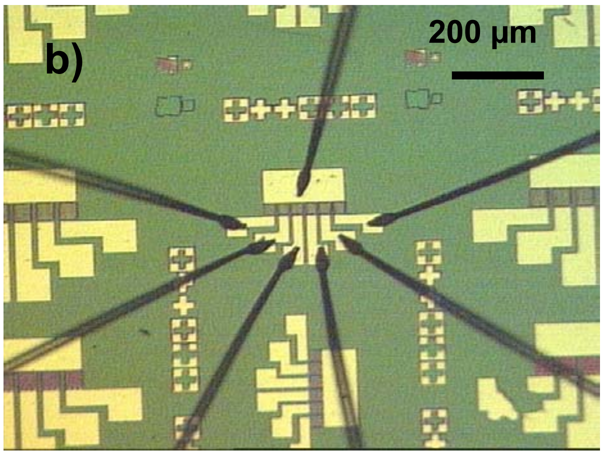
Title: ***Sistema de medida automatizado para fotoluminiscencia y dispersión Raman***
Author: Pedro Miguel Molleja Cabanas
Director: Álvaro Guzmán Fernández
Grade: Sobresaliente 9.0 p.
Date: May 28, 2003

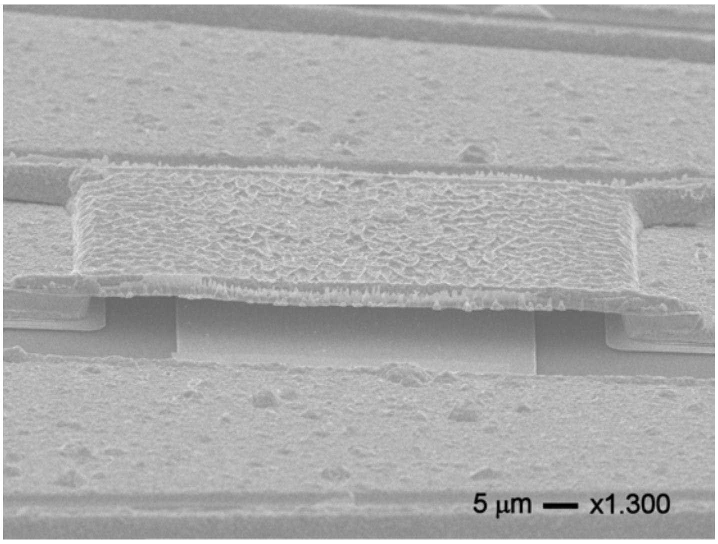
# R&D COLLABORATIONS, SERVICES AND SEMINARS



# 9. R&D COLLABORATION

## 9.1 International

- Centre de Recherche sur L'Hétéro-epitaxie et ses Applications, CRHEA-CNRS, (Valbonne, France)
- Cornell University (USA)
- Ghent University (Ghent, Belgium)
- INTEC/IMEC (Leuven, Belgium)
- Laboratoire d'Analyse et Aplications des Systèmes LAAS-CNRS, (Toulouse, France)
- National Microelectronics Research Center (Cork, Ireland)
- Northwestern University, (USA)
- Paul Drude Institute (Berlin, Germany)
- Technische Universiteit Eindhoven (The Netherlands)
- Thales (Thomson CSF), (France)
- The University of Sheffield (UK)
- University of Cambridge (UK)
- University of California, Santa Bárbara (USA)
- University of Colorado at Boulder (USA)
- Walter Schottky Institut - Technical University of Munich (Germany)
- West Virginia University (USA)

## 9.2 National

- Centro Nacional de Microelectrónica - Instituto de Microelectrónica de Barcelona IMB-CNM. CSIC
- Centro Nacional de Microelectrónica - Instituto de Microelectrónica de Madrid IMM-CNM-CSIC
- CIDA (Centro de Investigaciones de la Armada)
- CIEMAT (Centro de Investigaciones Energéticas y Medio Ambientales)
- INDRA SISTEMAS S.A.
- INTA (Instituto Nacional de Tecnología Aeroespacial)
- Mondragón Corporación Cooperativa (Ikerlan, Orkli…)
- SIMAVE S.A.
- TUDOR-EXIDE
- Universidad Carlos III de Madrid
- Universidad Complutense de Madrid
- Universidad de Barcelona, Dpto. Electrónica
- Universidad de Cádiz, Centro de Microscopía Electrónica
- Universidad de Oviedo.
- Universidad Politécnica de Madrid, SSR Department (ETSI. Telecomunicación)
- Universidad Rey Juan Carlos.

## 9.3 ISOM's members stays abroad

José María Ulloa Herrero
***"Thales Research and Technology"***

| | | | |
|---|---|---|---|
| Paris | France | 2002 | 3 months |

Esperanza Luna Gª de la Infanta
***"University of Sheffield"***

| | | | |
|---|---|---|---|
| Sheffield | United Kingdom | 2002 | 2 weeks |

Javier Miguel Sánchez
***"Electrical and Electronical Engineering Department of the University of Sheffiel" and "EPSRC national Centre for III-V Technologies"***

| | | | |
|---|---|---|---|
| Sheffield | United Kingdom | 2003 | 2 months |

Esperanza Luna Gª de la Infanta
***"Paul Drude Institut für Festkörperelektronik " (PDI)***

| | | | |
|---|---|---|---|
| Berlín | Germany | 2003 | 2 weeks |

## 9.4 Other R&D Activities

**Programme Committees Membership:**

Dr. Elías Muñoz Merino *Co-chairman/Organising*
Title: ***4th International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED´02) (Córdoba, Spain)***
Date: 2002

Dr. Enrique Calleja Pardo *Programme Chairman*
Title: ***4th International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED´02) (Córdoba, Spain)***
Date: 2002

Dr. Enrique Calleja Pardo *Session Chairman*
Title: ***Int. Workshop on Nitride Semiconductors, (IWN 2002) (Aachen, Germany)***
Date: 2002

Dr. Fernando Calle Gómez *International Advisory Committee*
Title: ***4th International Conference on Materials for Microelectronics & Nanoengineering, MFMN (Espoo, Finland)***
Date: 2002.

Dr. Fernando Calle Gómez *Secretary*
Title: ***4th International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED´02) (Córdoba, Spain)***
Date: 2002

Dr. Miguel Ángel Sánchez *Secretary and member of the Local Organizing Committee*
Title: ***4th International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED´02) (Córdoba, Spain)***
Date: 2002

Dr. José Luis Pau Vizcaíno *Local Committee member*
Title: ***4th International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED´02) (Córdoba, Spain)***
Date: 2002

Dr. Fernando Calle Gómez *General Chairman*
Title: ***12th European Heterostructure Technology Workshop, HETECH´03 (Segovia, Spain)***
Date: 2003

Dr. Miguel Ángel Sánchez *Local Committee member*
Title: ***12th European Heterostructure Technology Workshop, HETECH´03 (Segovia, Spain)***
Date: 2003

Dr. Enrique Calleja Pardo *Programme Committee member*
Title: ***12th European MBE Worshop (Bad Hofgastein, Austria)***
Date: 2003

## 9.5 *Invited Seminars held at ISOM*

***1.-*** Dr. **HOLGER GRAHN**
Paul Drude Institute for Solid State Electronics, Berlin, Germany
*"Electronic Band Structure and Polarization Properties of M-Plane GaN Films"*
May 17th, 2002

***2.-*** Dr. **PAULO SANTOS**
Paul Drude Institute for Solid State Electronics, Berlin, Germany
*"Dynamical modulation of GaAs quantum wells by surface acoustic waves"*
May 22nd, 2002

***3.-*** Dr. **ROSANA BADÍA**
Grupo de Biosensores, Dpto. de Química Física y Analítica, Universidad de Oviedo
"Tecnología Biomimética: Polímeros Impresos para el reconocimiento molecular en el desarrollo de sensores químicos"
Juliet 19th, 2002

***4.-*** Dr. **JOSÉ LUIS PRIETO MARTÍN**
University of Cambridge, Cambridge, UK.
*"Magnetorresistencia en paredes magnéticas"*
September 27th, 2002

***5.-*** Dr. **TADEK SUSKI**.
University of Warsaw, Warsaw, Poland.
*"High Pressure: an Important Tool in Basic Research and Technology of Group-III Nitrides"*
October 29th, 2002

***6.-*** Dr. **FERNANDO MORENO HERRERO**
Centro de Investigación y de Estudios Avanzados del IPN
*"Técnicas de microscopía de fuerzas para visualizar muestras biológicas en medio líquido"*
April 30th, 2003

***7.-*** Dr. **AXEL HOFFMANN**
Institüt für Festkörperphysik, , Universität Berlin, Germany
*"Exciton Dynamics in GaInAsN and InGaAs/GaAs Quantum Dots"*
May 5th, 2003

***8.-*** Dr. **JÜRGEN CHRISTEN**
Otto-von-Guricke- Universität Magdeburg, Germany
*"Physical Properties of High Quality GaN on Si"*
May 5th, 2003

***9.-*** Dr. **MARTIN EICKHOFF**
Walter Schottky Institute, Technische Universität München, Germany
*"GaN Field Effect Chemical Sensors"*
May 8th, 2003

***10.-*** Dr. **MAGALI ESTRADA DEL CUETO**
Centro de Investigación y de Estudios Avanzados del IPN
*"Nuevos dieléctricos para estructuras MOS submicrométricas"*
May 12th, 2003

***11.-*** Dr. **ANTONIO CERDEIRA ALTUZARRA**
Centro de Investigación y de Estudios Avanzados del IPN
*"El método de la función integral para la determinación de la distorsión armónica"*
May 12$^{th}$, 2003

***12.-*** Dr. **KLAUS PLOOG**
Paul Drude Institute for Solid State Electronics, Berlin, Germany
*"Are the Nitrides good for Everything?"*
June 2$^{nd}$ , 2003

# 10. COOPERATION AND SERVICES

- **Centre de Recherche sur L'Hétéro-epitaxie et ses Applications, CRHEA–CNRS (Valbonne, Francia)**
  Researchers: *Dr. P. Gibart and Dr. P. de Mierry*
  Research line: *Reflectivity Measurements for Bragg reflectors for LEDs*
  Researchers: *Dr. F. Omnes*
  Research line: *Materials for UV detectors and HEMT transistors.*
  Researchers: *Dr Z Bougrioua.*
  Research line: *Wafers for HEMT transistors.*

- **Centro de Investigación y Desarrollo de la Armada, CIDA**
  Researchers: *Dr. M.T. Montojo and Dr. G. Vergara*
  Research Line: *Far IR detectors*

- **Centro de Investigaciones Energéticas y Medio Ambientales, CIEMAT**
  Researcher: *Dr. J. Cárabe*
  Research Line: *Surface Measurements by SEM*
  Researcher: *Dr. M.T. Gutiérrez*
  Research Line: *Hall Measurements at different temperatures*
  *Resistivity Measurements*
  Researcher: *Dr. A. Martínez*
  Research Line: *SEM Measurements and compositional analysis by means of EDS*
  Researcher: *Dr. F.L. Tabarés*
  Research Line: *Plasma fusion wall interactions*

- **Dpto. Ciencia de Materiales, ETSI Caminos, Universidad Politécnica de Madrid**
  Researcher: *Dr. M. Elices, Dr. J.M. Atienza.*
  Research Lines: *Metallic evaporations*
  *SEM measurements*

- **Dpto. Ciencia y Tecnología de Materiales, Universidad Miguel Hernández, Elche**
  Researcher: *Dr. A.L. Álvarez*
  Research Line *Thickness measurements for organic films*

- **Dpto. Electrónica Física, ETSI Telecomunicación e Instituto de Energía Solar, UPM**
  Researcher: *Dr. C. Algora*
  Research Line: *PL measurements on materials for solar cells*
  *X-Ray diffraction measurements on materials for solar cells*
  *C-V characterization for solar cells*
  *Hall measurements*

- **Dpto. Química Analítica, Universidad de Oviedo**
  Researcher: *Dr. R. Badía*
  Research Line: *Polimers Deposition for Chemical Sensors.*

- **European Synchrotron Radiation Facility (ESRF), Grenoble (France)**
  Researcher: *Dr. G. Martínez Criado*
  Research Line: *Lithography*

- **Facultad de Ciencias Físicas, Universidad Complutense de Madrid**
  Researchers: *Dr. M.E. López Pérez and Dr. M.C. Sánchez Trujillo*
  Research Line: *Photolitography processes*
  *Surface and Structural Characterization*
  *Magnetic sensors*
  Researcher: *Dr. E. San Andrés*
  Research Line: *Ellipsometry measurements*
  *FTIR measurements.*

- **Instituto de Energía Solar, UPM**
  Researcher: *Dr. I. Rey-Stolle*
  Research Line: *Rocking-Curve Measurements*
  Researcher: *Dr. B. Galiana*
  Research Line: *Hall Measurements*

- **Instituto de Física Aplicada (CSIC).**
  Researcher*:* *Dr. I. Sayago*
  Research Line *Lithography*

- **Instituto de Estructura de la Materia (CSIC).**
  Researcher*:* *Dr. V.J. Herrero*
  Research Line *SEM Measurements.*

- **Universidad Complutense, CAI de Implantación Iónica, Madrid.**
  Researcher*:* *Dr. G. González*
  Research Line *Metallization processes*

- **Universidad Rey Juan Carlos, Madrid.**
  Researcher*:* *Dr. A.L. Álvarez*
  Research Line *Pulsed I-V measurements.*

# 11. SEMINARS

*1.-* Dª. Esperanza Luna García de la Infanta
***"Crecimiento y caracterización estructural de QWIPs de AlGaAs / AlAs / GaAs"***
February 22nd, 2002

*2.-* D. José Luis Ruiz Salazar
***"Introducción a la teoría de circuitos en alta frecuencia"***
July 26th, 2002

*3.-* Dª. Jelena Ristic
***"Crecimiento y caracterización de nanocolumnas de AlGaN y nanoestructuras de AlGaN/GaN/AlGaN"***
October 4th, 2002

*4.-* D. Fernando Naranjo Vega
***"El dopaje tipo p con Magnesio en GaN"***
October 18th, 2002

*5.-* D. José Luis Pau Vizcaíno
***"Sensores basados en nitruros orientados a la detección de llamas"***
October 25th, 2002

*6.-* Dª. Esperanza Luna García de la Infanta
***"Estudio mediante microscopía Electrónica de Transmisión de la influencia de las condiciones de crecimiento en el comportamiento fotovoltaico de detectores IR de AlGaAs/AlAs/GaAs con dopaje en el pozo"***
November 8th, 2002

*7.-* Dª. Susana Fernández Ruano
***"Estudio de la formación de cracks en reflectores de Bragg crecidos por MBE"***
November 15th, 2002

*8.-* Dª. Ana Jiménez Martín
***"Transporte electrónico en función de la polarización de puerta en HEMTs de AlGaN/GaN"***
November 22nd, de 2002

*9.-* Dª. Susana Fernández
***"DBRs: Nuevos diseños para incorporarlos en RCLEDs"***
November 30th, 2002

*10.-* D. José María Tirado
***"Efectos de dispersión en HEMTs de AlGaN/GaN"***
December 5th, 2002

*11.-* D. Javier Miguel Sánchez
***"Crecimiento por MBE de nitruros diluídos sobre GaAs"***
December 13th, 2002

**12.-** D. José Maria Ulloa.
***"Efecto del nitrógeno en la estructura de bandas y en la ganancia material de pozos cuánticos de InGaAsN/GaAs"***
Jaunary 17th, 2003

**13.-** Dª. Esperanza Luna García de la Infanta
***"Estudio del empleo de aleaciones de nitrógeno diluido, crecidas por MBE, en detectores de infrarojo de pozo cuántico y doble barrera para detección por debajo de 3.5 µm"***
March 7th, 2003

**14.-** Dª. Jelena Ristic
***"Euro-MBE 2003: Resumen de la conferencia"***
March 28th, 2003

**15.-** D. José Luis Pau Vizcaíno
***"Fotodiodos MSM & fotoconductores de AlGaN con alto contenido de A1"***
April 11th, 2003

**16.-** D. José María Ulloa
***"Efecto del aleado en las propiedades ópticas y estructurales de pozos cuánticos de GaInNAs/GaAs con altos contenidos de In y N"***
May 30th, 2003

**17.-** Dª. Susana Fernández
***"Efecto de las capas de AlN en las propiedades ópticas y estructurales de espejos de AlGaN/GaN"***
June 6th, 2003

**18.-** D. Lucas Pérez
***"Sensor magnético fluxgate planar con núcleo electrodepositado"***
June 20th, 2003

**19.-** D. Fernando Naranjo Vega
***"Crecimiento, fabricación y caracterización de diodos electroluminiscentes basados en pozos cuánticos de InGaN"***
September 26th, 2003

**20.-** Dª. Ana Jiménez Martín
***"Crecimiento y fabricacion de transistores HEMT de AlGaN/GaN por epitaxia de haces moleculares"***
October 2nd, 2003

**21.-** D. José Luis Pau Vizcaíno
***"Fabricación, caracterización y aplicaciones de detectores de UV basados en AlGaN"***
October 3rd, 2003

# 12. FUNDING INSTITUTIONS

- Airtel
- Comunidad Autónoma de Madrid
- Exide-Tudor
- European Regional Development Fund (ERDF)
- European Space Agency ESA-ESTEC
- Fifth and Sixth Framework Programme for Research and Technological Development (EU)
- INDRA SISTEMAS S.A.
- Ministerio de Ciencia y Tecnología
- Ministerio de Defensa-CIDA
- Mondragón Corporación Cooperativa
- Office of Naval Research (ONR-USA)
- ONERA (France)
- Secretaría de Estado de Educación, Universidades, Investigación y Desarrollo. Plan Nacional de I+D

# 13. MEMBERS

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