MORGaN

Materials for Robust Gallium Nitride
Newsletter #2 Jan-10

Welcome to the second MORGaN newsletter!

MORGaN is a project supported by the European Commission's Seventh Framework Programme to develop materials, processes and packaging for devices based on gallium nitride (GaN). The target applications are high power electronic devices and sensors for harsh environments.

In this newsletter we report on some exciting technology progress including improved GaN materials and GaN sensor development:

- Improved nanocolumns provide better GaN quality: striking images show the practical realisation of theoretical structures.
- Modelling behaviour of GaN cantilevers provides insight for pressure sensors designs
- Novel GaN "drumskin" pressure sensor design revealed.

More information may be found on the project website (www.morganproject.eu) which is kept up to date with all the latest news, and has many links to related technology and events. This newsletter is intended to provoke interest: please contact us if you have further questions: contact emails are given at the foot of the page.

Contents

Consortium

Project Leader : Sylvain Delage; Alcatel-Thales III-V Lab (sylvain.delage@3-5lab.fr)
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Website : www.morganproject.eu

Introduction to MORGaN 1

Objectives

• Development of sensor and RF transistor materials, processing and packaging for harsh environments, *e.g.* high temperature and high electric field

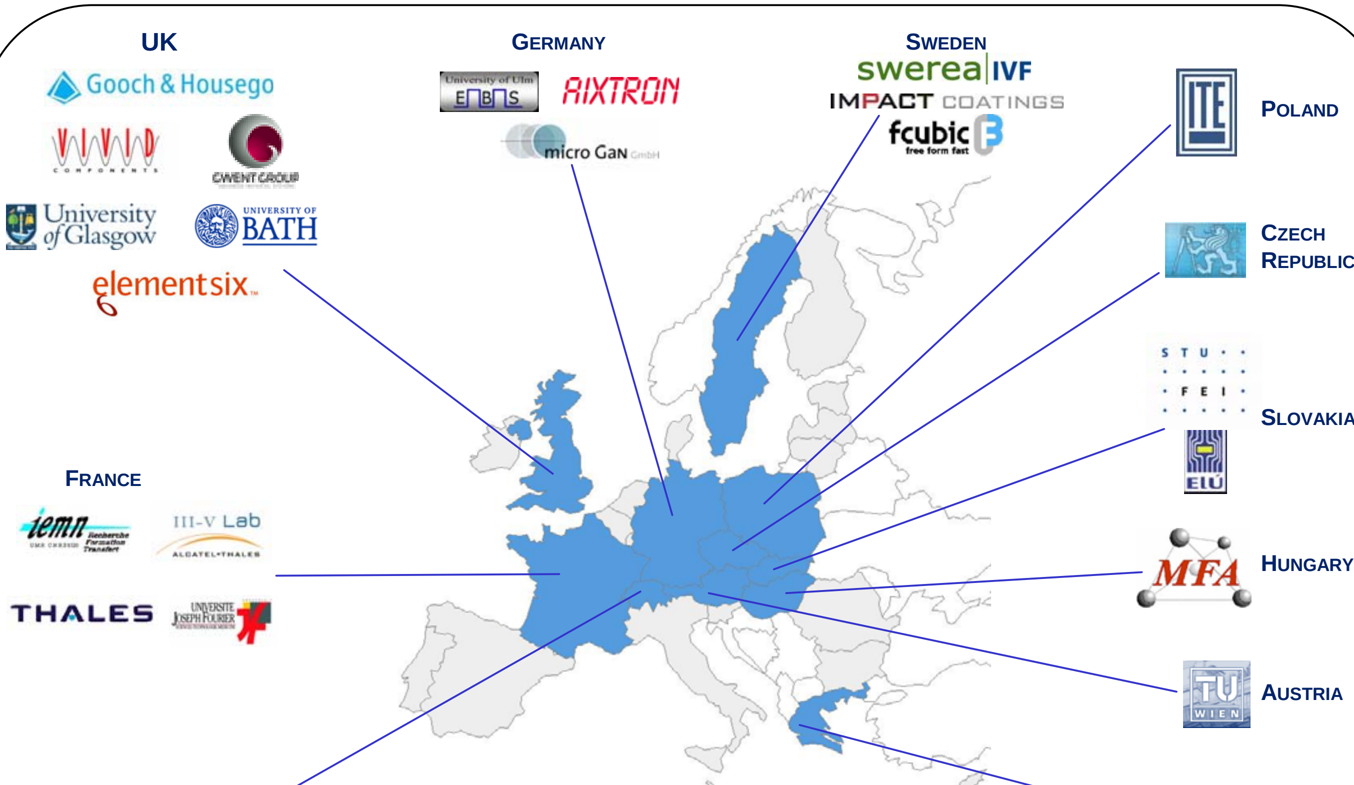
• Combining the properties of GaN and diamond promises world-beating materials for new applications & environments

- MORGaN will develop:
  - Innovative diamond-based composite substrates
  - Nanocrystalline diamond coatings for passivation and heat removal
  - Low stress and low defect density GaN films
  - Growth optimisation of InAlN/GaN heterostructures
  - Nitrides with high thermal and chemical stability
  - Packaging, interconnect and metallisation techniques.

Impact

- Strategic materials for European industry
- Improved devices for high power applications and harsh thermal or chemical environments:
  - Sensors in very high temperature environments (>500°C)
  - Aggressive wet chemical sensors for pH >15
  - Solid-state components compatible with 1kW power emission around 2GHz
- Key applications areas include:
  - Space and aerospace
  - Oil industry
  - Power generation
  - Automotive.

Consortium overview



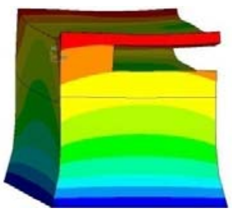
•24 partners; 11 nations

• Project lead organisation: Alcatel –Thales III-V Labs.

Introduction to MORGaN 2

The MORGaN project addresses the need for a new material basis for electronic devices and sensors that operate in extreme conditions, especially high temperature and high electric field. It aims to combine the excellent physical properties of diamond and GaN-based heterostructures to provide world-beating materials suitable for the latest industrial requirements. This broad-ranging project has four overlapping areas of study, which are outlined below:

III-V materials



MORGaN will directly explore a new $In_xAl_{1-x}N/GaN$ heterostructure developed in the FP6 UltraGaN project (www.ultragan.eu). This allows lower intrinsic mechanical stress, minimising material degradation mechanisms. A novel "nano-columns" technique developed at the University of Bath will also be used to grow low defect density GaN film.

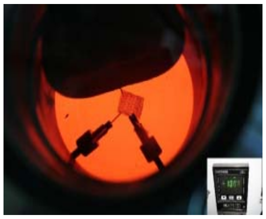
Using these technologies, MORGaN will develop polycrystalline diamond/Si sandwich hybrid substrates and compliant heterostructures for growing low defect density GaN film, including AlGaN alloys. It will also explore growth optimisation of InAlN/GaN heterostructures for electronic and sensing applications under extreme conditions.

Diamond-based materials

Diamond has the highest thermal conductivity of any solid, with values in high quality CVD diamond of ~2000$Wm^{-1}K^{-1}$. This makes it potentially the ultimate substrate for many high temperature and extreme power applications.

GaN alloys have demonstrated impressive power handling capability: performing from DC voltage to microwave operation with breakdown fields reaching over 5$MVcm^{-1}$. MORGaN aims to develop hybrids combining the excellent thermal behaviour of polycrystalline diamond with the electrical efficiency of GaN compounds. MORGaN will target the full potential of GaN without being limited by the thermal conductivity of GaN, or even SiC.

Harsh environment devices



Industry requires electronics to operate in increasingly harsh environments *e.g.*: extreme heat, pressure, large electric fields or chemically aggressive substances. Moreover, high power electronics generates internal harsh environments as a consequence of power dissipation from large current flow at high bias.

MORGaN will develop new semiconductor materials which are stable, especially at high temperature, and substrate and package combinations that enable rapid heat extraction and/or the capability to withstand high temperature. Chemical inertness is also key in highly corrosive environments.

Packaging and metallisation

Packaging & metallisation are essential considerations in extreme environments. Metal contacts must be stable, the package and device must be both thermally compatible and chemically stable. MORGaN will study a III-N material system with polycrystalline diamond-based substrates and nanocrystalline diamond heat spreading layers.

Advanced 3D ceramic packaging and new metallisation techniques based on the emerging technology of $M_{N+1}A_XN$ alloys will also be explored. Furthermore layer techniques may be used to manufacture very complex geometrical structures and MORGaN will develop new ceramics and metal system for high temperature applications.

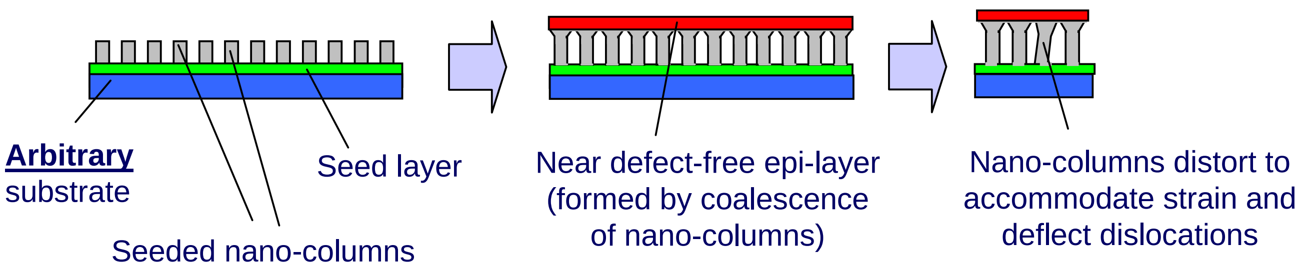
Project progress: III-V materials: Nanocolumns

UNIVERSITY OF BATH · FORTH · STU FEI

Objectives

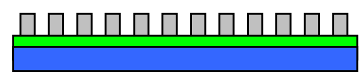
- Use a nano-column compliant layer between substrate (*e.g.* Si, sapphire) and epitaxy
  - Nano-columns act as a barrier to dislocations formed during GaN growth on a lattice-mismatched substrate
  - A continuous GaN layer overgrown on the nano-column compliant layer is potentially strain and dislocation free.

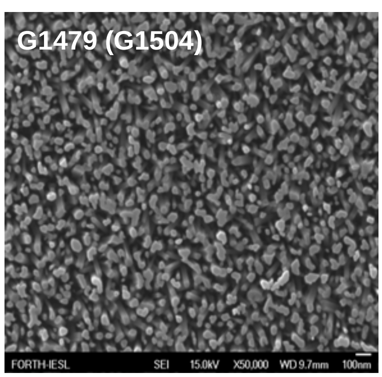
Schematic of nano-column compliant layer

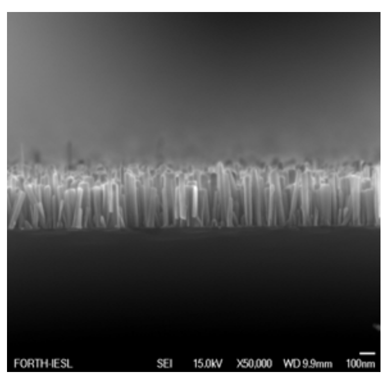


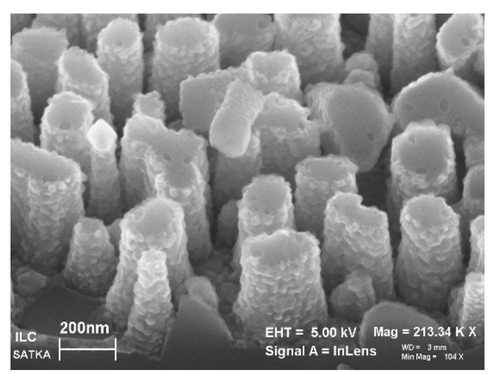
Realisation of nano-column compliant layer

These electron micrographs show the realisation of the predicted structures. The two images below left and centre show spontaneous growth of GaN nano-columns resulting from RF-MBE work performed at FORTH.



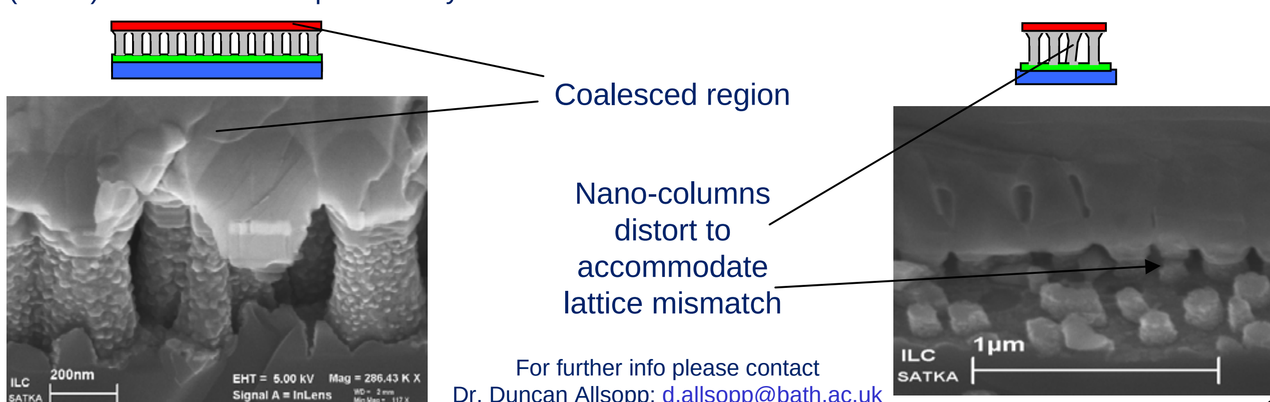






Plan view (FORTH) **Cross-section (FORTH)** **Cleaved nano-columns (Bath)**

The third image (above right) shows nano-columns formed using a novel over-growth technique developed at the University of Bath. Micrographs of cleaved wafers show coalesced nano-columns (below) with stress relief provided by the distorted nano-columns.

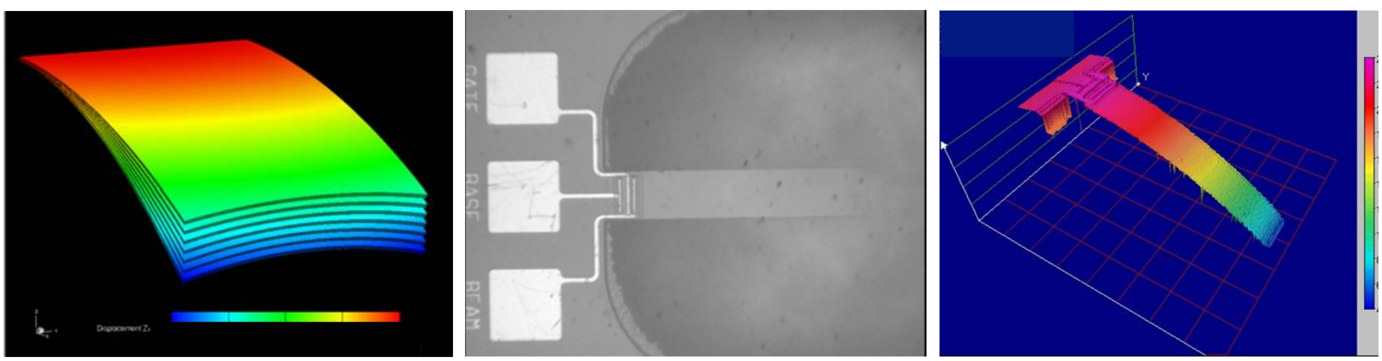


For further info please contact
Dr. Duncan Allsopp: d.allsopp@bath.ac.uk

Project progress: Physical properties and modelling

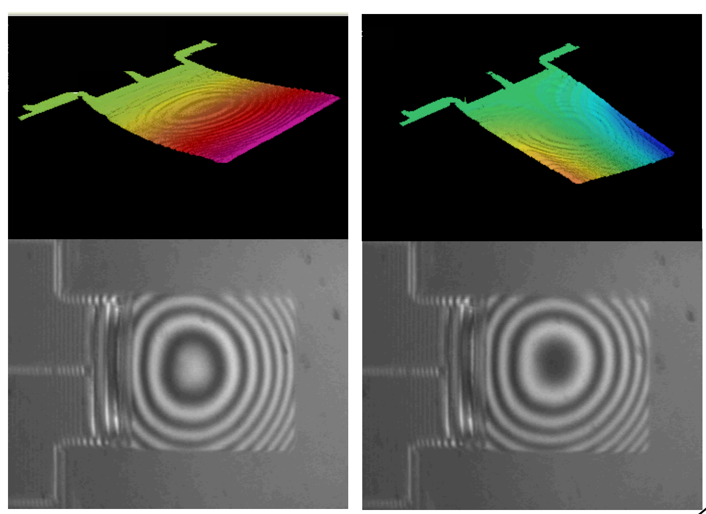
Objectives
- Static mechanical measurements of composite cantilevers
  - Estimation of the stress in the fabricated layers
- Harmonic behaviour of composite beam structures
  - Modelling and measurement
- Future mechanical simulations of the diamond cantilever overgrown with GaN.

Static mechanical measurements of composite cantilevers
- Study of cantilevers developed in the MORGaN project
- Different thicknesses and stresses exhibit different behaviour
- The study considered the effect of a global stress within the cantilever
- The global stress includes:
  - Thermal expansion coefficient mismatch
  - External stress (*e.g.* lattice mismatch, metal pads)
  - Intrinsic stress (*e.g.* interface quality, growth parameters, defects, dislocations)
- The model was compared with measured device characteristics using optical interferometry.



Computer-generated image of the modelled deflected cantilever for different stress values (left); optical microscope image of a MicroGaN GaN-based cantilever (centre); and the cantilever deflection measured using optical interferometry (right; with deflection exaggerated for clarity).

Harmonic behaviour of composite cantilevers
- Frequency variations of vibration modes as a function of initial stress were calculated
- Flexural and torsional modes were studied
- Good agreement with measured behaviour
  - Cantilever displacement as a function of frequency measured using oscillating piezo actuator
  - Mode shapes shown using optical interferometric techniques
- Elastic and shear moduli were derived.



Modelled and observed cantilever harmonic behaviour: first flexural mode (left) and first torsional mode (right). Resonant frequencies corresponded well with predictions for first and higher order modes.

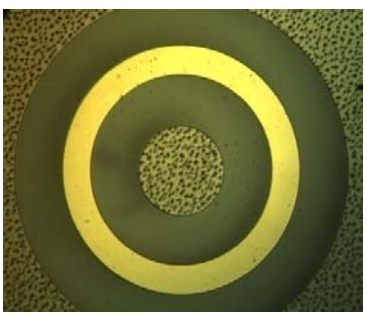
Project progress: Harsh environment sensors

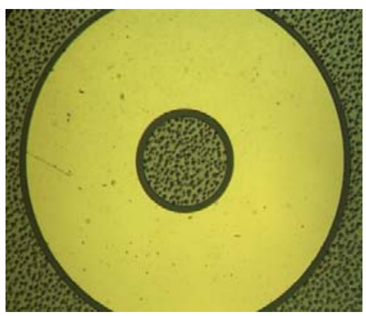
Objectives

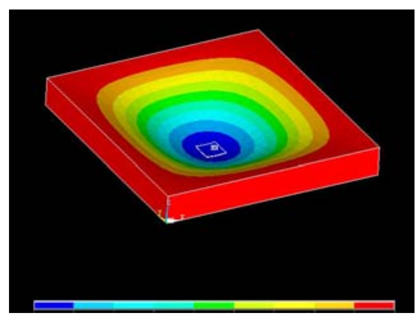
- Develop “drumskin” pressure sensor based on GaN
  - Alternative method to cantilever approach
  - HEMT sensor integrated into moving diaphragm structure
  - Potential advantages through simple manufacture and improved integration
- Sealing techniques for high temperature pressure sensors.

Drumskin pressure sensor

- An alternative design will be investigated in parallel with the cantilever approach based on a HEMT sensor directly integrated in the diaphragm
  - Diaphragm will be used for the detection of pressure with target range from 100 to 1000atm
  - Membrane strain is transferred to a GaN-based sensing device (AlGaN/GaN HEMT)
- Circular HEMT as a pressure sensing device is integrated in an AlGaN/GaN membrane
- There are several key advantages to this design
  - Simple C-HEMT fabrication and integration on membrane structure
  - Parasitic gate leakage current can be significantly suppressed
  - A large gate area can be easily achieved.

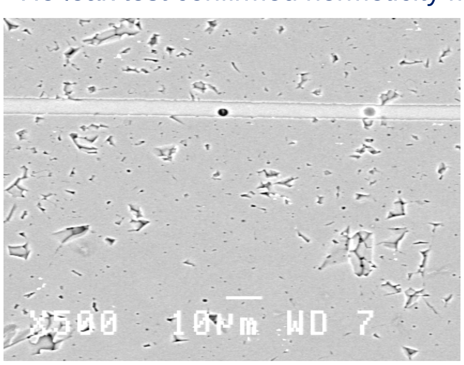






MORGaN high temperature pressure cell

- A MORGaN pressure cell has been designed and produced
  - External interconnects have been developed
  - Internal interconnects are under investigation
- Alumina-alumina seal tested at >1000ºC
  - He leak test confirmed hermeticity maintained.



Micrograph showing alumina-alumina seal on MORGaN pressure cell, tested to >1000ºC

Simple sintered alumina MORGaN pressure cell

Recent MORGaN events

12M project meeting; Kasteel Vaalsbroek, The Netherlands *19 & 20-Nov-09*
Aixtron A.G. organised an excellent meeting at a convenient local venue. A MORGaN group photo is shown below (note the diamond structure). The full agenda included break-out sessions for the planning and discussion of the many MORGaN topics.

Other events at which MORGaN work was presented
MORGaN members are actively engaged in many European events, and would be keen to answer questions on the project or forge new collaborations in this exciting technology area. Examples of recent events include:

- 4M Workshop, "Devices for harsh environments"; University of Vienna; 08-Jun-09
    - www.4m-association.org/event/4M-Workshop-Devices-harsh-environments
- SEPNET (South East Photonics Network) meeting; Havant, UK; Sep-09
    - http://sepnet.net/SEPNET_meetings.php
- 216th Meeting of the Electrochemical Society; Vienna Oct-09
    - http://www.electrochem.org/meetings/biannual/216/216.htm
- Slovak Ministry of Education “Centres of Excellence”; 05 to 08-Nov-09
    - IEE SAS was selected as a “Centre of Excellence” and displayed MORGaN material at the exhibition
- 18th European Workshop on Heterostructure Technology (see next page for more info)
    - www.hetech2009.org

Generic MORGaN presentation

- Please note that there is a generic MORGaN presentation which may be downloaded from the public website which discusses the aims and objectives of the project: http://www.morganproject.eu/outputs_public.htm

Recent MORGaN events

18th European Workshop on Heterostructure Technology

HETEC 2009 (www.hetech2009.org) was hosted by the University of Ulm (one of the MORGaN consortium) between 2-4 November 2009 at Ulm University Conference Centre: Schloss Reisenburg (pictured right).

Traditionally the main topics of the HETECH Workshops have been material processing technologies and the characteristics of electronic devices on III-V compound semiconductors and related heterostructures. However, in 2009, the scope of the Workshop was extended to include several novel MORGaN-related material configurations and device concepts, *e.g.* hetero-epitaxy of single crystal diamond films and bio-chemical sensing and optoelectronics.

The programme consisted of ten sessions, thirty six contributed papers and eleven invited talks. Key topics included:

- GaN Growth
- III-V Devices
- Advanced GaN HEMTs
- GaN Device Characteristics
- MEMS. Materials and Devices
- AlGaN/GaN HEMTs

The event was extremely well received by the 62-strong expert audience. Most of the invited papers (including several from MORGaN members) covered topics relevant to MORGaN. Amongst the highlights were the following papers:

- Alexandros Georgakilas (FORTH, Greece) *Progress in the heteroepitaxy of III-nitrides by plasma assisted MBE*
- Oliver Williams (IAF Freiburg, Germany) *Diamond Growth for MEMS applications*
- Matthias Schreck (University of Augsburg, Germany) *Single crystal diamond films on silicon: A semiconductor material for the formation of wide band gap heterostructures*

The 2010 HETECH Workshop will be organised by FORTH and is scheduled for October 2010.

Training activities

Internal MORGaN opportunities

Research Visit Applications

Are you a MORGaN researcher wishing to visit and collaborate with other MORGaN partners?

If so, you can apply for travel funds to visit other researchers!

The application form is simple and only a short follow up report is required after the training visit.

See above for examples of training which have been approved for 2010!

For application form and more information about these opportunities, please contact:
Dr. Chris Bowen (University of Bath)
c.r.bowen@bath.ac.uk

(Applications are assessed by the MORGaN training panel.)

Bratislava 2010 –
MORGaN Residential Workshop

This exciting training event will deliver seminars and practical workshops, in a focused residential course to be held **24-26 May 2010**. The course is hosted by the Faculty of Electrical Engineering & Information Technology (STU) with demos at the International Laser Centre and Slovak Academy of Sciences (IEE) set in the beautiful, historic city of Bratislava. **Attendance will be free for MORGaN researchers.**

Introductory talks will provide an overview of the MORGaN project and key research topics. The event will focus particularly on processing & characterisation, with invited speakers discussing the latest techniques, and practical demonstrations to support the material.

The 2010 MORGaN Residential Workshop will also provide an ideal environment for networking and showcasing the expertise that exists within the MORGaN consortium. Places are limited to ~20, so please register your interest at:

http://tinyurl.com/WP9-2009