MORGaN

Materials for Robust Gallium Nitride
Newsletter #1 Jun-09

Welcome to the first 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.

- The project started in Nov-08 and will run for three years.
- Twenty four partners from eleven nations
- Balance of academic & research organisations with large & small industrial partners
- Project lead organisation: Alcatel –Thales III-V Labs

This is the first of six newsletters to disseminate results of the project. 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.

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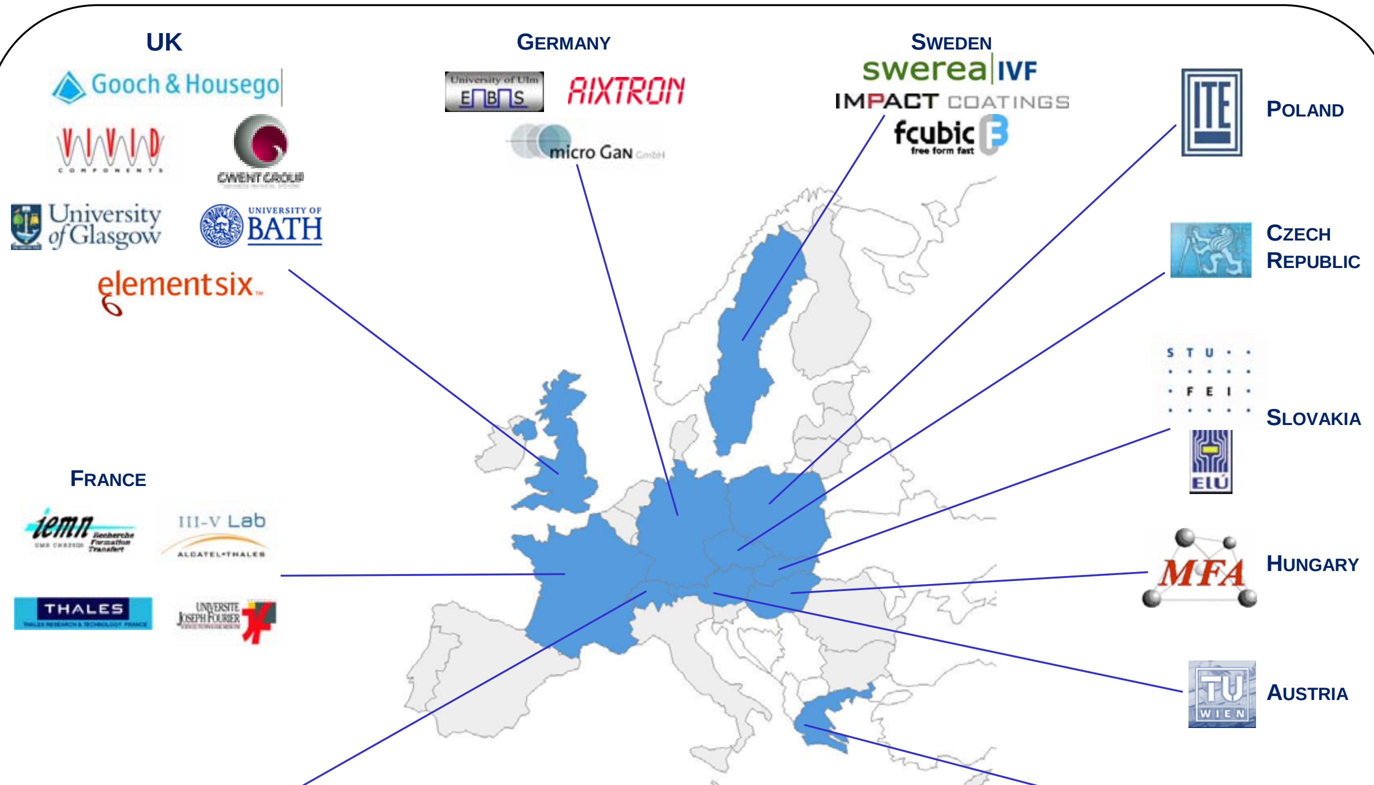
Objectives

- 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



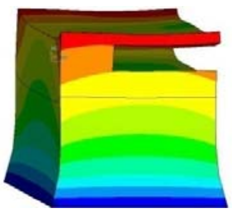
•24 partners; 11 nations

• 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.

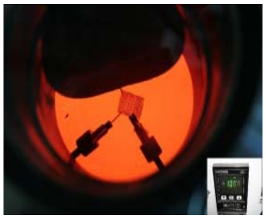
Using these technologies, MORGaN will develop polycrystalline diamond/Si sandwich hybrid substrates and compliant heterostructures for growing low defect density GaN film, including AlGaN alloys. It will also explore growth optimisation of InAlN/GaN heterostructures for electronic and sensing applications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

Objectives (AIXTRON Lead)

- Develop high quality InAlN/GaN heterostructures on:
  - SiC
  - Low cost substrates and hybrid substrates
  - Diamond
  - GaN-based compliant substrates
- Supply samples to MORGaN work areas for device processing, passivation and diamond coating
- Evaluation of epitaxial processes for mass production
- Detailed characterisation of epitaxial layers.

Progress towards objectives

High cost "traditional" substrates

- MOCVD process development for InAlN/GaN/SiC HEMT structures
- Samples on sapphire and SiC have been provided for MORGaN partners
- Start-up of new 3x2" or 1x4" Close Coupled Showerhead MOCVD reactor at AIXTRON

Low cost and hybrid substrates

- MOCVD development of AlInN-HEMTs on Si (111) substrates
- Investigation of RFMBE growth of GaN films on Si (111) substrates
- AlInN-HEMTs on Si (111) delivered to MORGaN partners

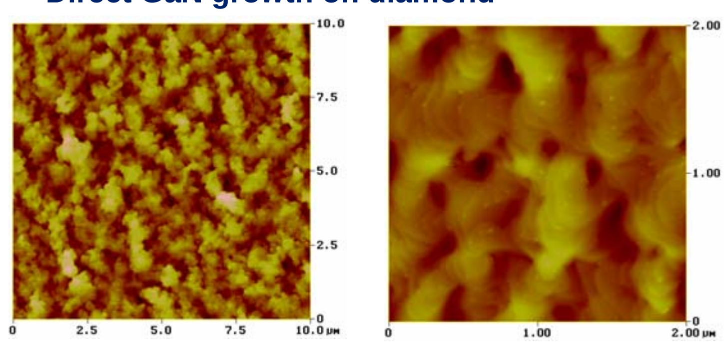
Direct growth on diamond

- RFMBE hetero-epitaxy of GaN on single crystalline (100), (111) and (110) diamond substrates (see below)
- First demonstration of GaN growth on single crystal diamond with different surface orientations

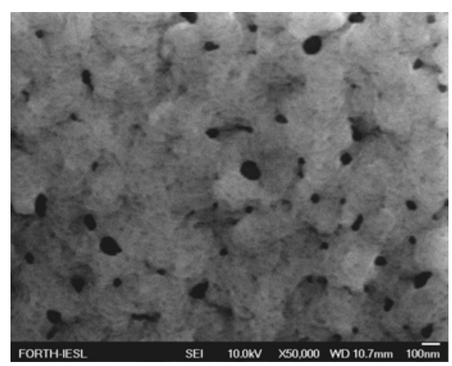
Epitaxial validation

- MOCVD process development for GaN deposition on 6" Si (111) substrates
- Simulation of InAlN growth on 4" substrates in multi-wafer MOCVD reactor.

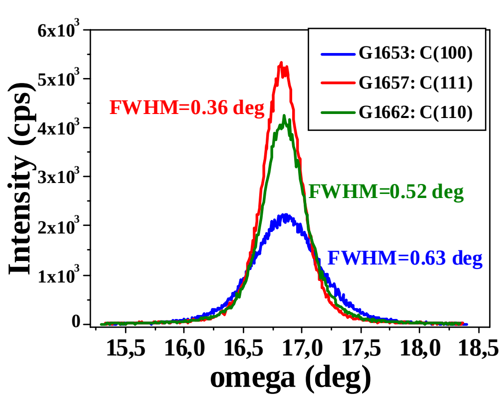
Direct GaN growth on diamond



Relatively smooth GaN surfaces for all diamond orientations (100, 110, 111) have been realised (RMS roughness: 2.57nm).



SEM image revealing steps of GaN surface



- *XRD rocking curves suggest better GaN structural properties on (111) and (110) diamond orientations*
- *Lowest FWHM of (0002) RC was 0.36º for diamond (111)*
- *Lowest FWHM of asymmetric (10-15) RC was 0.14º and 0.15º for (100) and (110) orientations, respectively.*

Project progress: Diamond-based substrates for GaN

Objectives (E6 Lead)

- Provide a high thermal conductivity substrate for III-N epitaxial growth
- Evaluate three technology solutions:
    - Polycrystalline diamond
    - Single crystal diamond
    - Diamond-on-Si composite (DOSC) wafers
- Develop and provide advanced surface treatments
- Characterise substrates and surfaces.

Progress towards objectives

Diamond for direct growth

- First batches of single crystal and polycrystalline diamond wafers supplied to MORGaN consortium
- High quality surface finish

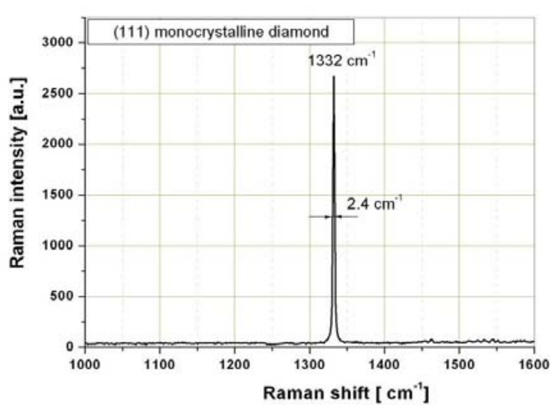
DOSC substrates

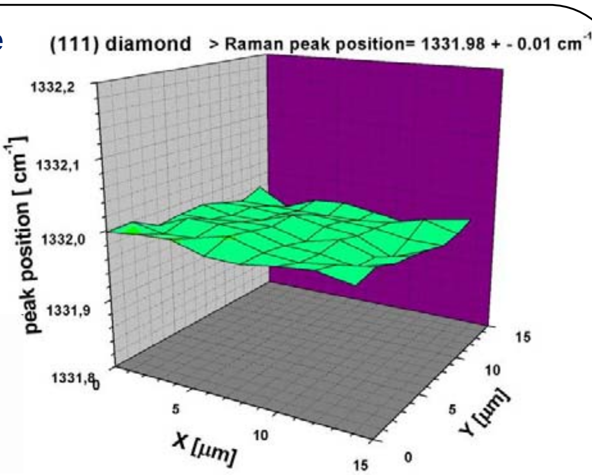
- Diamond on Si CVD development on schedule: routine production of prototype wafers established
- Processing development on schedule: Si thinning progressing using mechanical lapping techniques
- First wafers available for testing

Substrate characterisation

- Characterisation of polycrystalline and (100) and (111) orientated single crystal diamond substrates
- Crystal quality and homogeneity evaluated by TEM and micro-Raman spectroscopy (see figures below)
    - Very high quality single crystal samples (defect-free in local TEM investigations)
    - Polycrystalline wafer exhibited large (20μm) high quality diamond grains with different crystallographic orientations
    - Regions of higher proportions of non-diamond carbon detected at grain boundaries by Raman
    - TEM study revealed a network of dislocations near the surface of the wafer
        - Possibly a result of the grinding/polishing process
- AFM and SEM of polycrystalline wafer shows relief due to hardness differences between grain orientations exposed by polish.

Micro-Raman spectroscopy of diamond substrate





Results of micro-Raman spectroscopy of (111) single crystal diamond substrate. The left hand graph shows the Raman spectrum, and the right hand graph is a map of the Raman peak position showing excellent homogeneity.

Project progress: Physical properties and modelling

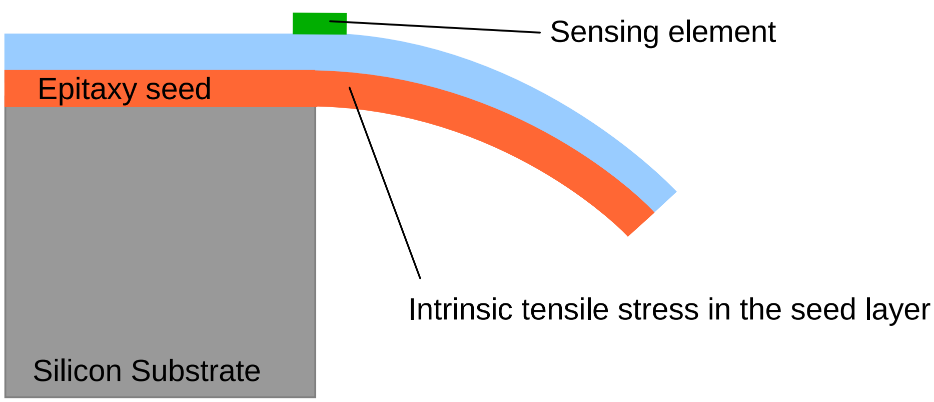
Objectives (TUW Lead)

- Analysis of physical properties of materials developed in MORGaN
  - Thermal-mechanical
  - Piezoelectric
- Simulation and modelling of MORGaN materials and devices
  - Design input for demonstrator devices
    - Sensors
    - Power electronics
    - Study of device degradation mechanisms.

Progress towards objectives

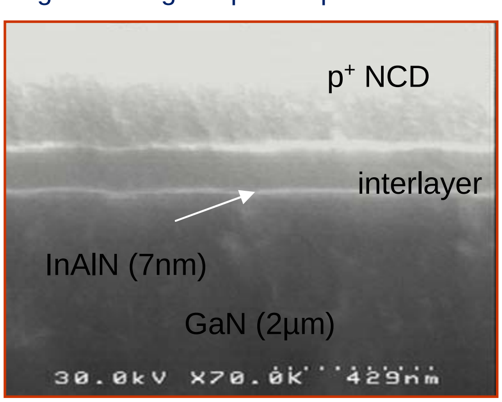
Simulation of a cantilever with a strain resulting from the epitaxial growth

- Creation of a simulation model for GaN-based cantilevers with a tensile stressed seed layer
- Thermo-mechanical simulations were performed on a cantilever structure
  - Several different substrates were considered.



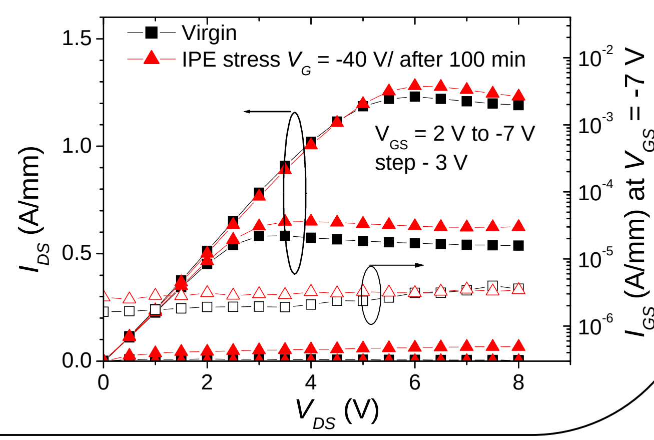
Verification of a new concept of an ion sensitive FET

- Growth of a boron-doped nanocrystalline diamond layer on AlInN barrier
- ISFET with epoxy passivation: reproducible pH sensing in a range of pH1 to pH13.



Degradation study

Inverse piezoelectric effect does not affect the InAlN/GaN HEMT because there is no strain in the barrier itself.



Project progress: Harsh environment sensors

Objectives (MicroGaN Lead)

- Validate quality of GaN-based devices for sensor applications
    - *E.g.* temperature, pressure and chemical sensors devices
- Characterisation over wide temperature range
- Integrated and packaged device demonstration.

Progress towards objectives

Device designs for harsh environment

- Review of applications requiring electronics in harsh environments
    - A short exercise to confirm the latest industrial requirements for electronic components, including sensors. Industries covered include power, aerospace, chemical and food. The results will help ensure that the MORGaN work is well aligned with industrial need.
- Simulation study of cantilevers with the aim to increase the sensitivity of the sensor
- Investigation of HEMT piezo-response on a bulk sapphire substrate
- Design and fabrication of ELOG - GaN cantilevers
- Fabrication and characterization of AlGaN/GaN-on-Si cantilevers
- Design and fabrication of a lithography mask for the optimisation of ISFETs on nitride

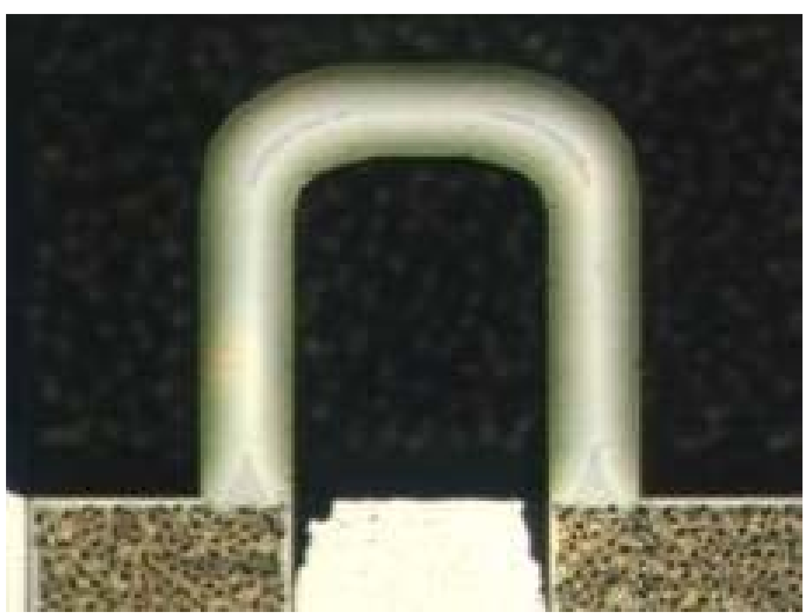
Devices performance in harsh environments

- Study of high-temperature performance of HEMT strain sensors
    - The temperature stability of nitrides and device reliability will be investigated.
    - Bonding techniques for high temperature applications will be evaluated.

Double-clamped mechanical sensor developed in the MORGaN project

A double-clamped AlGaN/GaN-on-silicon cantilever structure is shown on the right.

Heterojunction field effect transistors are used to detect the deflection of the cantilever.



Recent MORGaN events

6M project meeting; Bath, UK *05 & 06-May-09*

The University of Bath organised an excellent meeting at a local venue. The full agenda included break-out sessions for the planning and discussion of the many MORGaN topics. As can be seen from the photo, the meeting was well attended by cheerful and eager MORGaN members!

Examples of other relevant events attended by MORGaN members

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:

• Living with Thermal Management: Applications in Harsh Environments, Oxford, UK; 05-Mar-09

    • Workshop/ roadmapping event for end users and suppliers

    • www.faraday-advance.net/index.asp?PageID=69

• FOHEC 2009 Yeovilton, UK; 07-May-09

    • Fibre Optics for Harsh Environments Conference

    • www.fohec.co.uk

•WOCSDICE 09, Malaga, Spain; 17-20 May-09

    •33rd Workshop on Compound Semiconductor Devices and Integrated Circuits

    • www.wocsdice2009.org

•4M Workshop, University of Vienna; 08-Jun-09

    • "Devices for harsh environments (materials, processing, characterisation)“

    • www.4m-association.org/event/4M-Workshop-Devices-harsh-environments

Upcoming MORGaN events

18th European Workshop on Heterostructure Technology

- 2-4 November 2009
- Ulm University Conference Centre: Schloss Reisenburg
- Günzburg, Ulm, Germany
- First Announcement and Call for Papers: www.hetech2009.org
- Extended abstract deadline: 13 July 2009

The workshop is organised by a key MORGaN member (University of Ulm). It is intended to bring together young scientists, engineers and post-graduate students working in the field of compound semiconductor and other heterogeneous technologies, focusing on materials and devices for electronics, optoelectronics and sensing. Topics covered include novel material configurations and novel device concepts including MORGaN, but also other breakthrough areas such as nano-wire devices and bio-chemical sensing.

For more info please contact: hetech2009@uni-ulm.de

38th International School and Conference on the Physics of Semiconductors

"Jaszowiec 2009" Krynica-Zdrój, Poland; 16-26 Jun-09

- This will include a presentation by MORGaN members
  - "Ti3SiC2 thin films as Schottky barriers for III-N HEMT applications"
- For more info please see: http://info.ifpan.edu.pl/Jaszowiec

Training activities

Internal MORGaN opportunities

1. 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!

2. HeTech 2009 *2-4 Nov 2009*
Ulm University Conference Centre
www.hetech2009.org
(See above for more details!)

The MORGaN project will support up to five MORGaN Ph.D. students to attend HeTech 2009.

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

(Applications are assessed by the MORGaN training panel.)

Bratislava 2010 – MORGaN Residential Course

This exciting training event will deliver seminars and practical workshops, in a focused 3-day residential course in January 2010.

The course is hosted by the Faculty of Electrical Engineering & Information Technology (STU) with demos at the Slovak Academy of Sciences (IEE) set in the beautiful, historic city of Bratislava.

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

It will also provide an ideal environment for networking and showcasing the expertise that exists within the MORGaN consortium. Places are limited, so please register your interest at:

http://tinyurl.com/WP9-2009