MORGaN- Materials for Robust Gallium Nitride

- The MORGaN project is supported by the EC under FP7
  - Project website: www.morganproject.eu

- Key objectives
  - Develop GaN sensors & RF transistors for harsh environments
    - Materials
    - Processing
    - Packaging
  - Combine the properties of GaN and diamond
    - Promises world-beating materials for new applications & environments.

Why GaN?

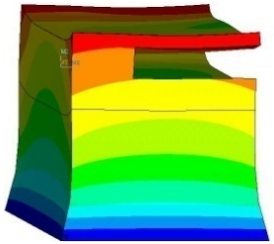
- GaN offers key advantages over traditional semiconductors
  - Thermal & chemical stability
    - Operation at >1000ºC demonstrated
  - Wide bandgap and high breakdown voltage
- Potential for step change technology improvements
  - Power electronics
  - Harsh environment sensors

- However GaN infrastructure and processing needs development
  - Limited wafer availability
  - Material quality problems
    - Imperfections & intrinsic material strain

- MORGaN will develop several promising solutions
  - Novel diamond substrates and passivation
  - New growth techniques
  - Associated packaging and interconnect development.

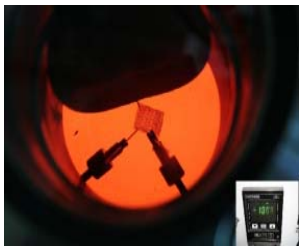
MORGaN topics

1.) III-V materials
- Improved GaN films
  - Low stress and low defect density
  - Growth optimisation of InAlN/GaN heterostructures

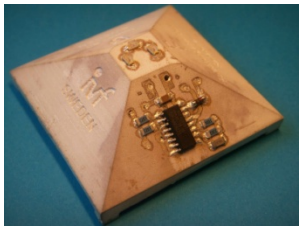


2.) Diamond-based materials
- Innovative diamond-based composite substrates
  - Combine the properties of GaN and diamond
  - Nanocrystalline diamond coatings for passivation & heat removal

3.) Harsh environment devices
- High power electronic devices
- Sensors for harsh environments



4.) Packaging and metallisation
- Packaging, interconnect and metallisation techniques
  - For harsh environment applications.



MORGaN consortium

UK

Gooch & Housego

VIVID COMPONENTS

CWENT GROUP

University of Glasgow

UNIVERSITY OF BATH

element six

GERMANY

University of Ulm EBS

AIXTRON

micro GaN GmbH

SWEDEN

swerea IVF

IMPACT COATINGS

fcubic free form fast

POLAND

CZECH REPUBLIC

STU FEI

SLOVAKIA

ELÚ

HUNGARY

MFA

AUSTRIA

TU WIEN

GREECE

FORTH

FRANCE

iemn Recherche Formation Transfert

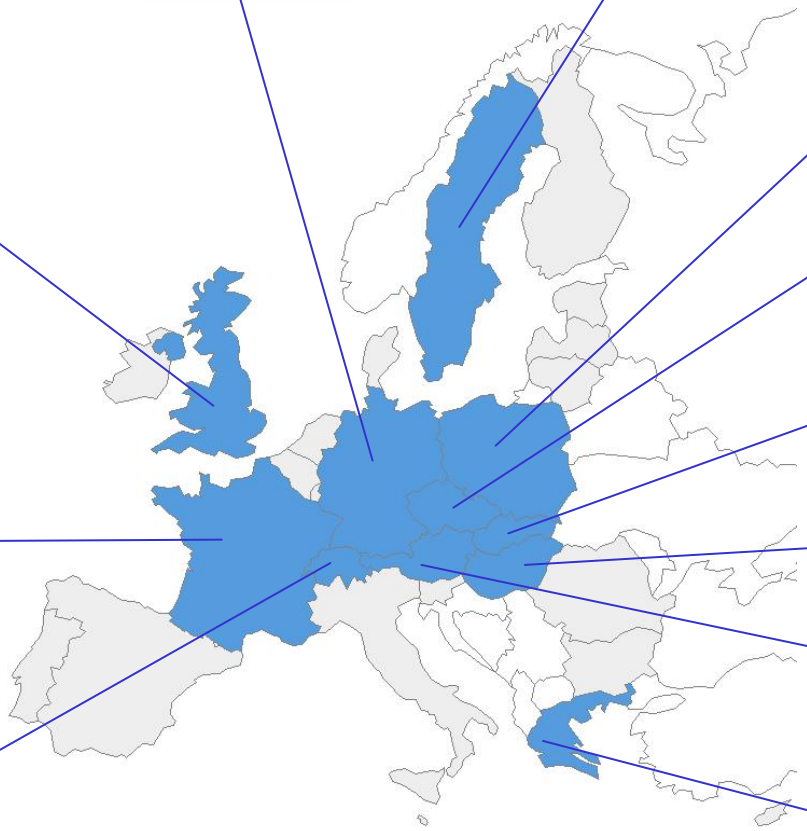
III-V Lab ALCATEL-THALES

THALES

UNIVERSITE JOSEPH FOURIER

SWITZERLAND

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

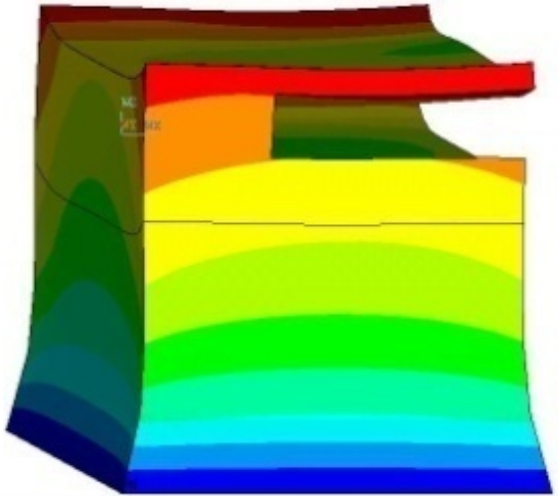


•24 partners; 11 nations

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

1.) III-V materials

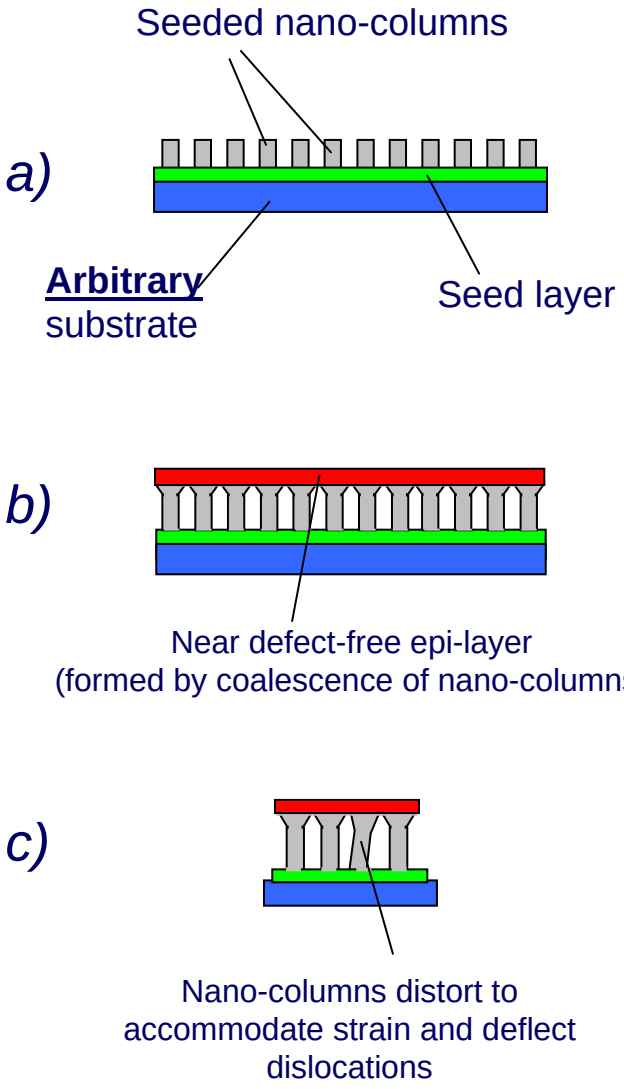
- MORGaN objectives
  - New substrates for low defect density GaN
    - Polycrystalline diamond/Si sandwich hybrid substrates
    - Compliant heterostructures for growing GaN film
  - Growth optimisation of InAlN/GaN heterostructures
    - Harsh environment electronic & sensing applications
- MORGaN novel approaches
  - New $In_xAl_{1-x}N$/GaN heterostructures
    - Lower intrinsic mechanical stress
    - Minimises material degradation
    - Originally developed in FP6 www.ultragan.eu
  - “Nano-columns" technique
    - Developed at the University of Bath
    - Used to grow low defect density GaN film.



MORGaN technology 1
Nano-columns 1

- Objective:
  - 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

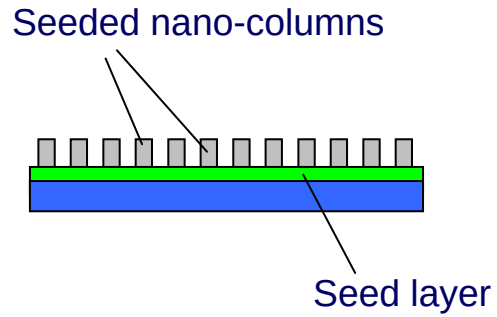
- A continuous GaN layer overgrown on the nano-column compliant layer is potentially strain and dislocation free.

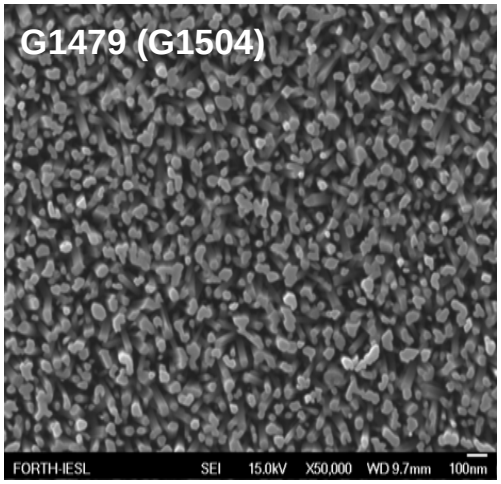


MORGaN technology 1
Nano-columns 2

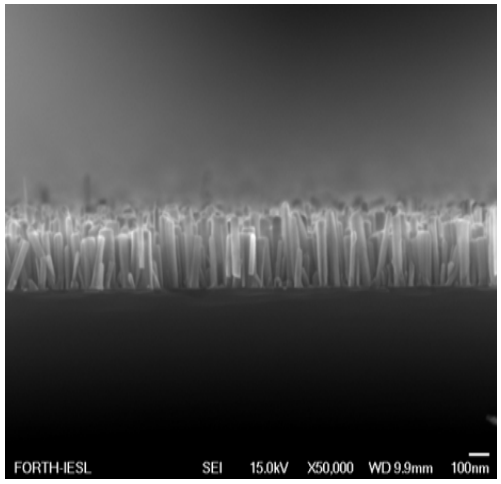
- Electron micrograph showing spontaneous growth of GaN nano-columns
  - RF-MBE
  - Work performed at FORTH

a)

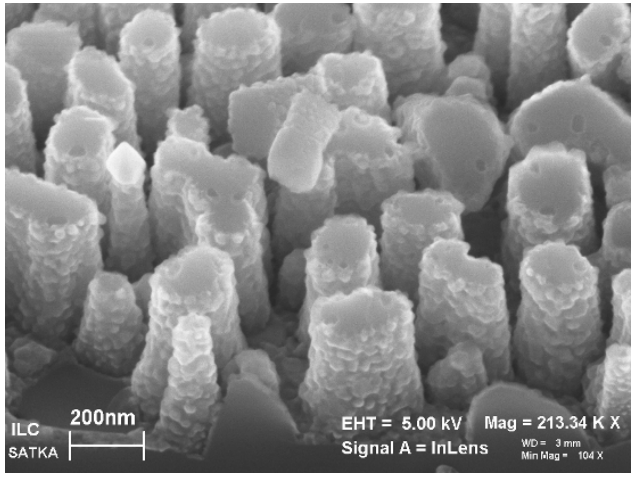




Plan view



Cross-section

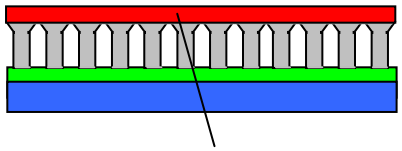


Cleaved nano-columns

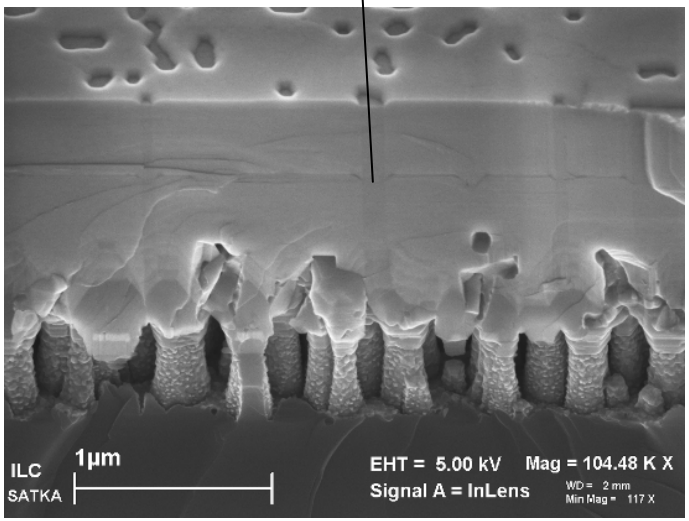
MORGaN technology 1
Nano-columns 3

- Overgrowth of nano-columns by MOVPE at University of Bath
  - Micrographs of cleaved wafer showing coalesced nano-columns

b)



Coalesced region



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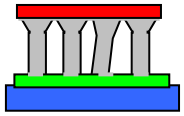
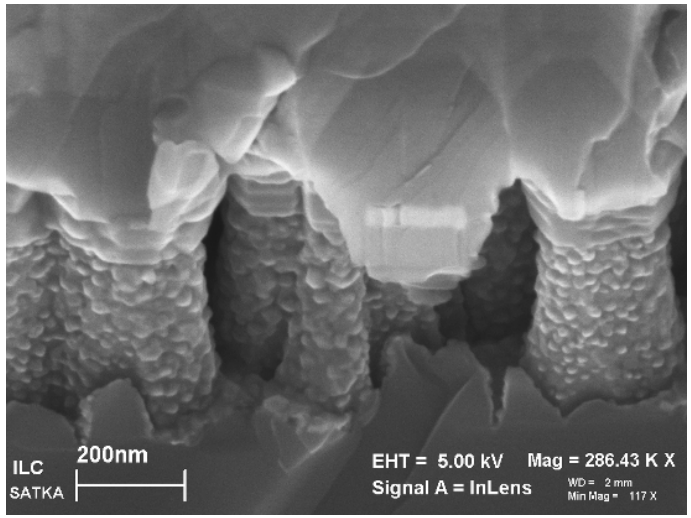




Structural cross-section

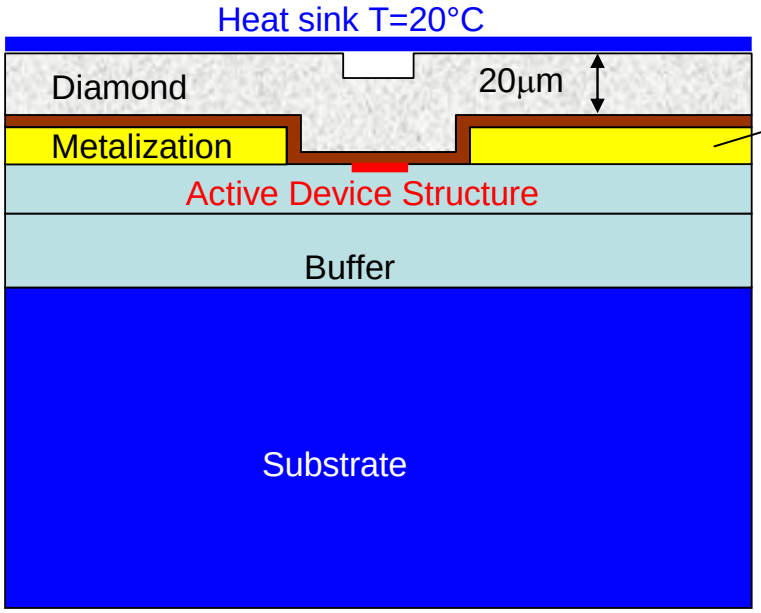
2.) Diamond-based materials

- Diamond
  - Highest thermal conductivity of any solid
    - ~2000$Wm^{-1}K^{-1}$ in high quality CVD diamond
  - Potentially the ultimate substrate for high temperature & extreme power applications
- GaN alloys
  - Impressive power handling capability
    - DC to microwave operation with breakdown fields >5$MVcm^{-1}$
- MORGaN will develop diamond/ GaN hybrids
  - Thermal behaviour of diamond
  - Electrical efficiency of GaN
  - Realise the full potential of GaN without being limited by its thermal conductivity.

MORGaN technology 2

Nano-crystalline diamond coating 1

- Diamond overgrowth for thermal management
- InAlN/GaN HEMT offers thermal stability of heterostructure and contacts
- Large area diamond overgrowth
  - Polycrystalline diamond deposition by hot-filament CVD



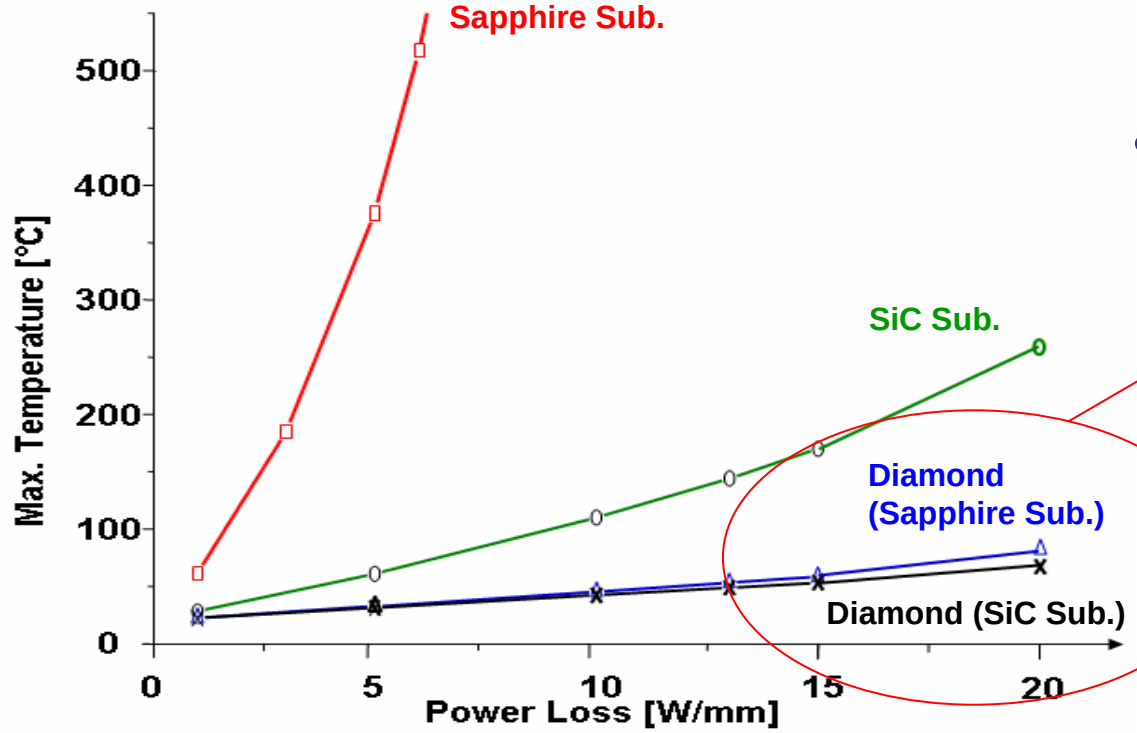
Si_3N_4 passivation
(30 - 100nm)

- NB Harsh growth conditions!
  - Hydrogen radicals at 800°C for several hours.

MORGaN technology 2

Nano-crystalline diamond coating 2

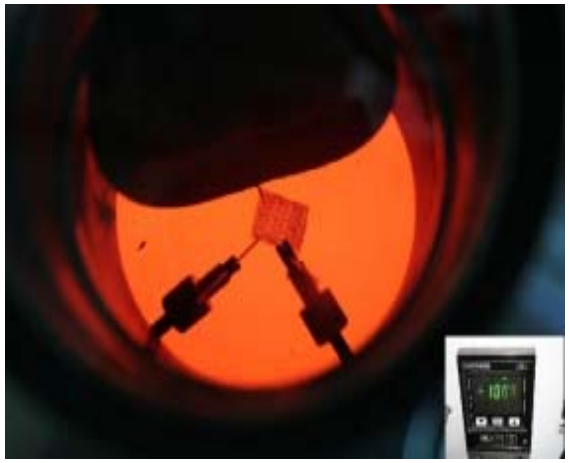
- Graph shows effectiveness of diamond heat spreader
  - Simulation of performance of sapphire and SiC
    - With and without diamond coating



- Substrate choice almost irrelevant!

3.) Harsh environment devices

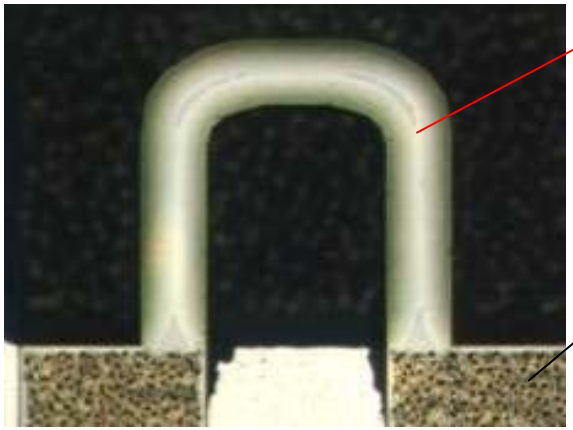
- "External harsh environment"
  - Increasing industrial demands for electronics
  - Operation required in increasingly harsh environments
    - Extreme heat
    - Pressure
    - High electric fields
    - Chemically aggressive substances.
- "Internal harsh environment"
  - Modern high power electronics generates extreme temperatures
    - Power dissipation from large current flow at high bias
- MORGaN will develop
  - Semiconductor materials
  - Substrates
  - Packaging
- High temperature stability
- Rapid heat extraction
- Chemically inert.

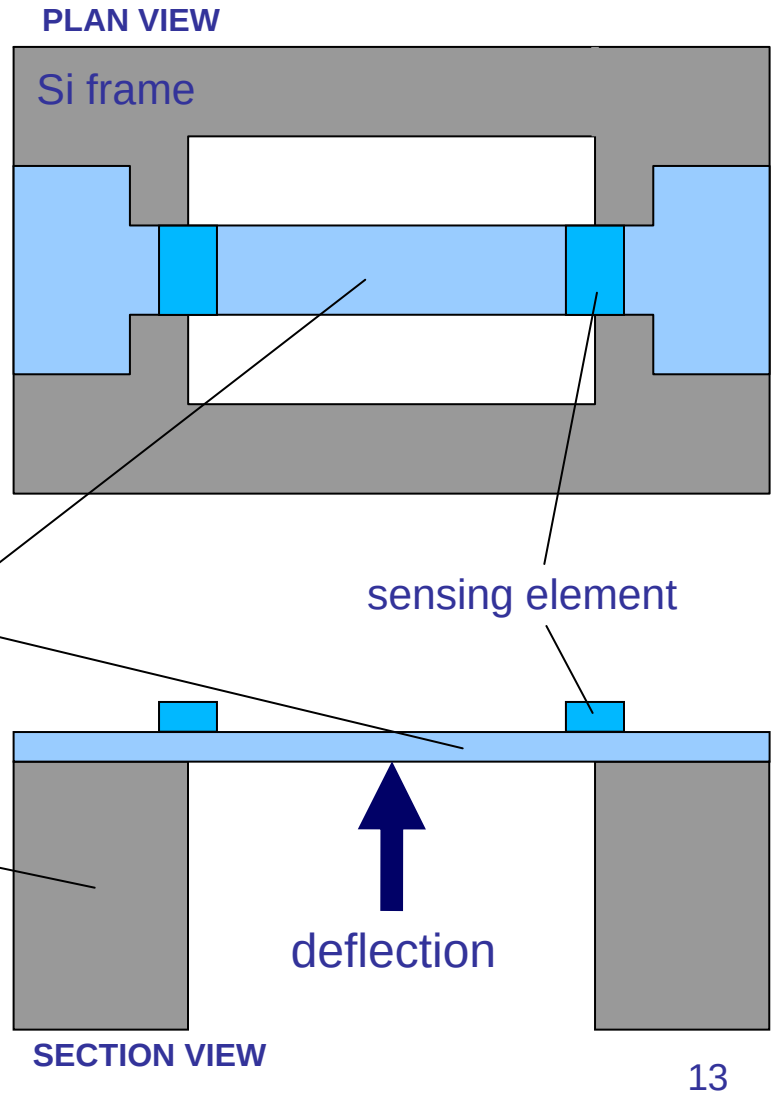


MORGaN technology 3

Cantilever pressure sensor

- Double clamped beam
  - Beam is initially flat
  - Sensing element located at beam edge
    - Highest stress point
  - Si frame maintains mechanical stability
  - High signal expected even at low deflections
- Many geometries possible
  - e.g. photo shows high mechanical stability design with additional mount points.

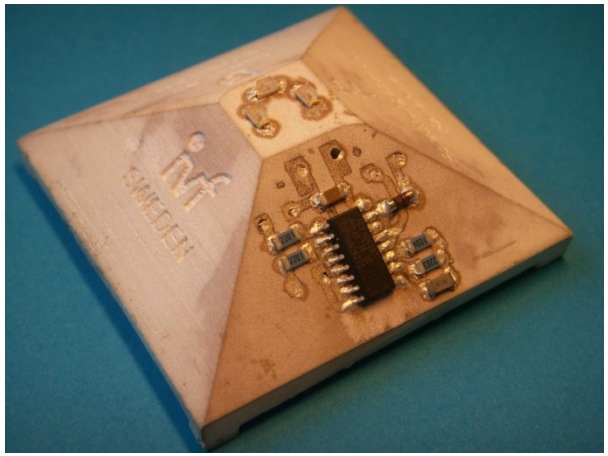




4.) Packaging and metallisation

- Packaging & metallisation
  - Essential considerations in extreme environments
  - Must be thermally stable and compatible
  - Chemically stable

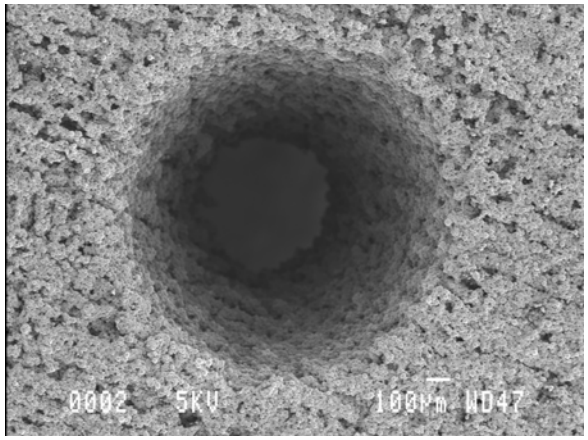
- MORGaN novel approaches
  - III-N material system
    - Polycrystalline diamond-based substrates
    - Nanocrystalline diamond heat spreading layers.
  - Advanced 3D ceramic packaging
  - New metallisation techniques
    - Emerging technology of $M_{N+1}A_XN$ alloys
  - Novel layer package manufacture techniques
    - Permit very complex geometrical package and interconnect structures
  - Ceramic/ metal systems for high temperature applications.



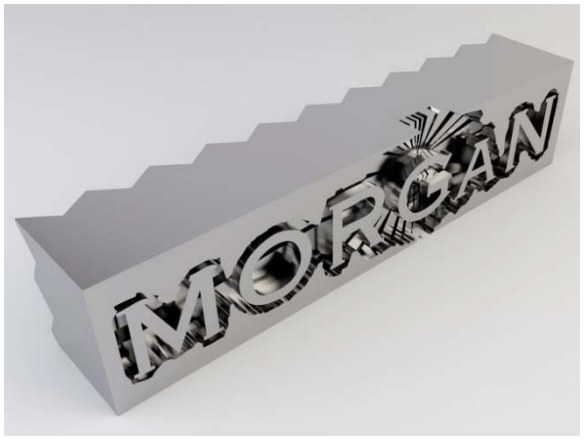
MORGaN technology 4

Layer manufacturing

- Novel process to produce steel parts using ink-jet technology
  - Process uses a fine stainless steel powder (316L)
  - Sintered to full density
  - Other steels & metals (*e.g.* Ti) also possible
  - Resolution *c*. 20μm (*x*,*y*); 40μm (*z*)
  - Surface finish *c*. 4μm
- Large geometric freedom
  - Complex shapes for novel packaging possible.



PRE-SINTERED "GREEN" PART



MORGaN training opportunities

- MORGaN offers many training opportunities
  - Ph.D. students
    - Advanced and emerging knowledge on thesis topics
    - Wider technological context
  - Established researchers and technologists
    - Wide scope for new skills & information

- Residential course
  - Bratislava January 2010
  - Hosted by STU and IEE
  - Advanced instruction on core MORGaN topics
  - See http://tinyurl.com/WP9-2009

- Workshop
  - To be held in the second half of the project

- Research visits between MORGaN partners
  - Extended research visits (1-12 weeks duration)
  - Postgraduate student/ experienced researcher level.

MORGaN contact information

- For more information:
  - Project leader
    - Sylvain Delage; Alcatel-Thales III-V Lab
    - sylvain.delage@3-5lab.fr
  - Dissemination
    - Bruce Napier; Vivid Components
    - bruce@vividcomponents.co.uk
  - Website : www.morganproject.eu
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