200mm GaN-on-Si CMOS compatible platform

DENIS MARCON, PH.D.

SEPT 2014
Who is Imec?

- Founded in 1984
- **Non-profit organization** with a revenue of >300MEuro (80% industry)
- **2100 Scientists from 77 countries**
- **Delivery industrial-relevant R&D** and **technology** solutions:
  - Advance CMOS scaling
  - Life-science
  - Energy
  - Communication
  - ...
- **Open innovational model**
RESEARCH PROGRAMS FOR FULL ECO SYSTEM

**Energy**
Photovoltaics, GaN Power and LEDs device

**Human++**
BAN Life Sciences

**Green Radio**
Low power wireless communication

**Imaging**
Image sensors & vision systems

**Sensor systems**
for industrial applications

**Core CMOS**
Lithography Devices Interconnects

**CMORE**
MEMS, Sensor Photonics

**Organic electronics**
Power supply evolution enabled by GaN-based tech.

- Current converters
- Higher efficiency
- High frequency
- Low RonQg
- High integration
- Smaller size
- Future Converters
  - Highly efficient
  - Highly compact

For illustration purpose
Power electronics market and wideband gap material

IT & Consumer
- PFC/power suppliers for home appliance, white goods, pc, notebook etc....

Automotive
- DC/DC converter DC/AC
- Inverter for Hybrid Automotive, Electric vehicle etc...

Industry
- Inverter for PV, Motor Control, Power distribution, train etc....

200V 600V 1200V >2000V

GaN

Competition

SiC
GaN-on-Si power semiconductor market prediction

GaN-on-Silicon Power Semiconductor Market

Data Source:
The World Market for Silicon Carbide & Gallium Nitride Power Semiconductors – 2013
GaN Industrial Affiliation Program (IIAP)

Mission
To deliver advanced industrial (R&D) 200mm GaN-on-Si CMOS technology
Imec offers an integrated R&D Platform on a state of the art infrastructure

**Epitaxy**
- GaN epilayer growth
- Si3N4 passivation layer
- N isolation implant
- Gate area patterning
- Gate dielectric deposition
- Gate electrode definition
- Ohmic area patterning
- Ohmic metal definition
- Ohmic alloy
- Metal interconnect levels

**Device Design**
- Device Processing
- Measurements
- Qualification & Rel.
More than 10 years on GaN-on-Si

- **2001**: 100 mm GaN-on-Si Std III-V devices
- **2009**: 150 mm GaN-on-Si CMOS Comp. devices
- **2011**: 200 mm GaN-on-Si CMOS Comp. devices
- **2013**: 200 mm GaN-on-Si CMOS Compatible platform (e-mode, d-mode, diodes)
- **2007**: 150 mm GaN-on-Si wafers
- **2010**: 200 mm GaN-on-Si wafers
- **2009**: 150mm GaN-on-Si CMOS Compatible
- **2011**: 200mm GaN-on-Si CMOS Compatible
- **2001**: 100mm GaN-on-Si
**IMEC 200mm GaN-on-Si Platform overview**

<table>
<thead>
<tr>
<th>MISHEMTs</th>
<th>MISHEMTs</th>
<th>J-HEMTs</th>
<th>Schottky</th>
<th>NO&lt;sub&gt;x&lt;/sub&gt;</th>
<th>LED</th>
<th>RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Mode transistors</td>
<td>E-Mode transistors</td>
<td>Diodes</td>
<td>Power Devices</td>
<td>Sensors</td>
<td>Lighting</td>
<td>Telecom</td>
</tr>
<tr>
<td>CMOS compatible processing modules</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GaN-on-Si epitaxy</td>
<td></td>
<td></td>
<td>HR-Si</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200mm GaN-on-Si platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
200mm GaN-on-Si epitaxy challenges

- (Al)GaN and Si have different lattice constant and thermal expansion coefficient
- If the epitaxy is not properly engineered, the mismatches between the materials can result in:
  - Excessive wafer bow
  - Large defect density
  - Surface pits
200mm GaN-on-Si epitaxy

Buffer has been optimized to obtain:

- Low defect density
- No pits
- Good uniformity

Smooth and pit-free GaN-epi surface
200mm GaN-on-Si epitaxy: Reproducibility of XRD data

Reproducibility of buffer quality
High quality (Al)GaN buffer are well reproducible wafer after wafer
200mm GaN-on-Si epitaxy: Reproducibility of BOW data

Reproducibility of buffer quality
High quality (Al)GaN buffer are well reproducible wafer after wafer
200mm GaN-on-Si (Al)GaN buffer for High breakdown voltage

(Uniform) buffer leakage at 1100V less than 1µA/mm
Control of Ga contamination

Effective cleaning procedure of the backside of the GaN-on-Si wafers

- Ga is p-type dopant for Si and shall not be spread in a CMOS fab
- Imec has developed procedures to keep the Ga contamination under control

Ad-hoc effective cleaning procedure of the etching tools
Au free ohmic contacts

• Typical III-V process uses Au that is forbidden in CMOS fab
• At imec we have obtained Au free ohmics that are:
  • As good as std Au containing ohmics (Rc < 0.5 ohm mm)
  • Uniform and reproducible
  • Reliable
E-mode GaN-on-Si technology

• GaN-based HEMTs are normally-on (d-mode)

• Market/Industry wants normally-off (e-mode)
  • Recess MISHEMTs
  • Junction-HEMTs
Recess GaN MISHEMT

Normally-on (d-mode) MISHEMT

a. Barrier Recess
b. Gate dielectric
c. Gate metal

Normally off (e-mode) MISHEMT
Recess GaN MISHEMT

Normally-on (d-mode) MISHEMT

Normally off (e-mode) MISHEMT

a. Barrier Recess  b. Gate dielectric  c. Gate metal
(Main) Challenges on Recess GaN MISHEMT technology

- **Recess technology:**
  - Tight control of recess depth
  - Low induced damages

- **Gate (dielectric) technology:**
  - Low interfaces traps density (cleanings etc...)
  - Low bulk traps density (dielectric quality etc...)
  - Pre/post treatments

*Recess and gate technology have a strong impact on device uniformity (Vth etc...) and performance (Ids, Ron etc...)*
Results on GaN recess MISHEMT

Imec GaN e-mode MISHEMTs:
- Tight $V_{th}$ distribution
- $V_{th} > 1V$
- $I_{ds} < nA/mm$ at $V_g=0V$

Forward gate leakage
- Breakdown $> 15V$
- Below $1nA/mm$ at $10V$
- 1% failure 20years lifetime at $150^\circ C$ for $V_{gmax} = 8V$
Breakdown characteristic of GaN recess MISHEMT

Breakdown characteristic measured on a 18mm power bar at Vg = 0V
Impact of the gate dielectric technology

Dielectric technology with high Dit

Dielectric technology with low Dit

On recess MISHEMT technology the interfaces and border traps at the dielectric/(Al)GaN interface play a key role on the device performance
200mm GaN-on-Si Imec Schottky diodes combine
- Low turn-on voltage
- Low reverse leakage current
Conclusion

• Imec has been working on GaN-on-Si for more than 10 years providing industrial relevant R&D

• Imec’s 200mm GaN-on-Si platform is available for current and future partners
ASPIRE INVENT ACHIEVE
NO₂ sensors