**Defect Metrology of Epitaxial Ge on Patterned Si Wafers Using an Inline HRXRD Tool**


a) Jordan Valley Semiconductors, 3913 Todd Lane, Suite 106, Austin, TX 78744, USA
b) SEMATECH, 257 Fuller Road, Suite 2200, Albany, NY 12203, USA
c) Jordan Valley Semiconductors, Zone #6, Ramat Gavriel, Migdal Ha’Emek 23100, Israel
d) Novelli Technologies, 2706 Montopolis Drive, Austin, TX 78741, USA

**Abstract**

The shift from the desktop to mobile computing devices puts ever increasing demands on CMOS technology to offer even lower power consumption and higher performance. High mobility channel materials such as Ge and III-V are strong contenders to replace Si at the sub-10 nm technology nodes. The intricately higher carrier mobility and injection velocity of these materials have the potential to enable the same level of scaling of the power supply voltage (Vdd) without compromising performance. These materials, however, must be integrated on Si substrates to take advantage of Si-based high-volume manufacturing (HVM) platforms. However, direct deposition of Ge or III-V on Si results in a highly defective material due to the large lattice mismatch with the Si substrate (> 4%). One promising integration approach is to use "aspect ratio trapping (ART)" where the mismatched material is grown within trenches patterned in SiO2 with aspect ratios sufficient to confine the dislocations to the lower part of the trench. With development, this is a promising approach to produce material with sufficiently low defect density for nanoelectronic devices. High-resolution X-ray diffraction (HRXRD) is an established technique for the characterization and metrology of epitaxial thin films such as Ge and III-V by the compound semiconductor industry and is also used for R&D and in-line process control in Si-based HVM. In this work we describe the use of an in-line X-ray metrology tool for the characterization of defectivity in Ge ART structures. The defect densities obtained using a more traditional reciprocal space mapping (RSM) method are also shown to be consistent with those of transmission electron microscopy (TEM) performed on the same samples.

**Introduction**

Compound semiconductors have higher carrier mobility, narrower bandgap and lower effective mass than Si.

- Ge & III-V are TEMs that mitigate the performance and subthreshold leakage trade-off in Si CMOS: Lower leakage currents and variability with robust control of channel-length effects
- High-speed performance at lower supply voltage
- Significant challenges for growth of Ge on Si:
  - High-mismatch (±1%) typically leads to highly defective films
  - Polar films on non-polar substrates -> antiphase boundaries (APBs)

**TEM Analysis**

- Plan-view and cross-sectional TEMs were collected to provide complementary information about defect distribution:
  - Plan-view TEMs showing a cross-section of the patterned trenches in the Ge layer, which were patterned by lithographic patterning and plasma dry etching.
  - Cross-sectional TEMs showing a cross-section of the patterned trenches in the Ge layer, which were patterned by lithographic patterning and plasma dry etching.

**HRXRD Analysis**

- HRXRD measurements were done using a Jordan Valley FAST200 X-ray metrology tool:
  - 0.5 x 0.5 μm Ge x-ray tube and double-layer curved crystals (DCC) optic used to produce a convergent beam focused on the sample. Beam has a divergence angle of 10" and is used in a small focused spot of about 5 μm
  - Linear (10) detector measures the entire diffraction/reflected intensity is parallel to the sample surface
  - Data from small test pads or products can be collected with a detector focused in measurement time (about 10x) compared to conventional parallel-beam diffractometers with a similar spot size
  - Fully automated measurement and analysis with various background options and 3D/4D data for Si and Ge

- Measurements of the symmetric 004 002 Bragg reflection were done using the FastHRXRD tool in which the incident beam s was opened wide and the reflected intensity distribution was acquired simultaneously in about 30 s

- Additional, reciprocal space maps (RSMs) were collected by:
  - Calculating the position of the beam so that the intensity from the beam is open and the incident beam divergence is about 0.2°
  - Rotating the wafer so that the beam is aligned with the incidence from the 002 line with respect to the substrate peak position without changing the spot position on the detector
  - Acquiring the intensity over a range of about 4° with the 10 detector at each step

**Summary & Conclusion**

We have demonstrated the capability of an inline HRXRD metrology tool to monitor the defect density of ART samples by studying pitch defects and aspect ratios. The defect density extracted from HRXRD is comparable to the values obtained using RSMs and TEM analysis. With a typical measurement time of ~30 seconds, this tool provides fast and non-destructive feedback to support optimization of the ART processes in the R&D phase; it is also expected to enable fabrication yield and time-to-market of ART processes at the wafer level. The ART structures also provide high-resolution structural metrology as well as thickness of the coalesced Ge layer. In particular, when the Ge trench width is increased from 150 nm to 350 nm, the dominant defect type changes from threading dislocations to stacking faults. The post-CMP coalesced Ge layer also becomes thinner as the trench is widened.

**References**