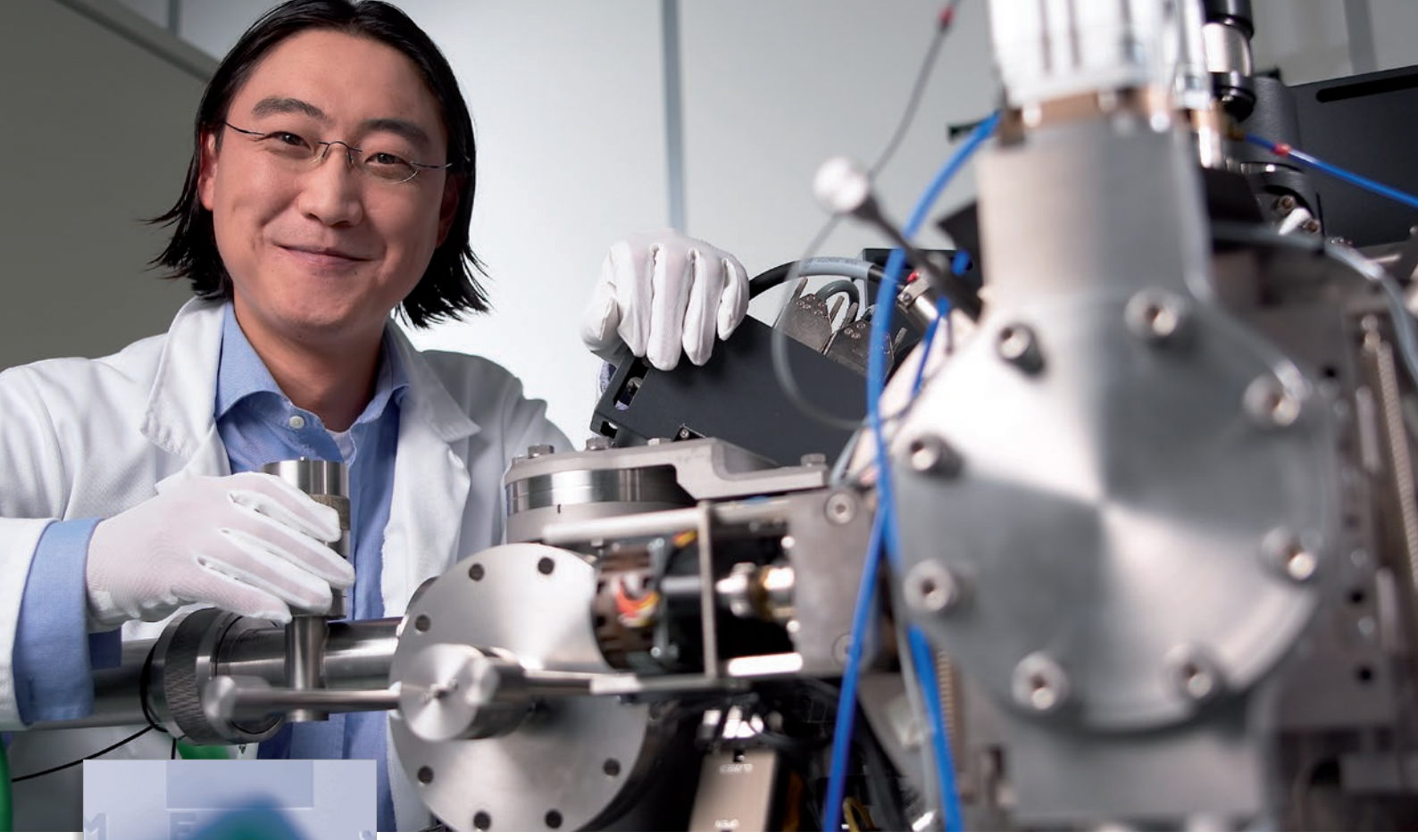

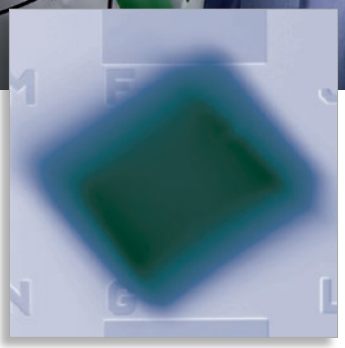

Secondary Ion Mass Spectrometry

- semiconductors
- dopant profiling
- implantation control
- metal traces
- all elements (H-U)
- high sensitivity

For all semiconductor products, from IC's to solar cells to LED's, it is crucial to control the concentration depth profiles of dopants and contaminants. Secondary Ion Mass Spectrometry (SIMS) is the most important technique for measuring depth profiles of all elements with extreme sensitivity, huge dynamic range and very good depth resolution. The technique is also used to measure dilute element profiles in specialty glasses, ceramics, and metal alloys, and –by measuring isotope ratios– in art history, geology and extra-terrestrial research.

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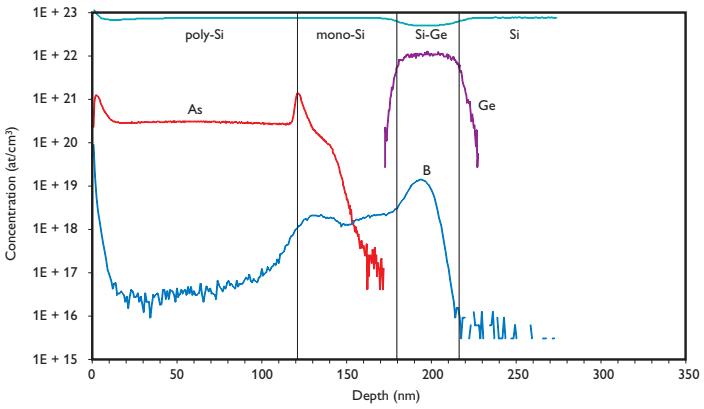

Fig. 1: Concentration depth profiles of As, B and Ge in a process control module with the same layer stack and dopant profiles as the active area of a bipolar transistor.

Principle

In Secondary Ion Mass Spectrometry (SIMS), the sample is bombarded in ultra-high vacuum with a beam of energetic ions ('primary ions'). Atoms and clusters of atoms are sputtered away from the sample, part of them in an ionized state ('secondary ions'). The ionized fraction is analyzed in a mass spectrometer. If the primary beam is rastered over the area of interest, a flat-bottomed crater is gradually formed and meanwhile the intensity of a secondary ion signal as a function of sputtering time is measured. By suitable calibration measurements, this can later be translated into a concentration depth profile. This application of SIMS is referred to as 'dynamic' SIMS or SIMS depth profiling.

SIMS is performed in positive or negative mode, i.e. detecting positive or negative secondary ions. To enhance the secondary ion yield, either O_2^+ (positive mode) or Cs^+ primary ions (negative mode) are used. Thus, a detection limit of 1 ppb can be achieved for many elements. For the elements present in the residual gas of the vacuum chamber (e.g. H, C, N and O) the detection limits are higher. All elements can be analyzed, including hydrogen. The different isotopes can always be distinguished.

A typical application

The active part of a fast-switching bipolar transistor contains a single crystalline stack of Si / Si_xGe_{1-x} /Si (see figure 1). The p-type dopant Boron is included during layer growth. The n-type dopant Arsenic is introduced by deposition of an As-doped poly –crystalline Si layer. Upon a thermal anneal, the As and B dopants diffuse, yielding the profiles shown in figure 1. The shape of the As and B dopant profiles and their position with respect to the Si_xGe_{1-x} layer are very critical for the performance of the transistor. To define the position of the pn-junction, it is essential to measure the n- and p-type dopant depth profiles simultaneously with the Ge concentration depth profile. Figure 1 is an example of such a measurement. One wafer is taken out of a production batch just before back-end processing (i.e. electrical connects through metal lines and vias). SIMS measurements are performed on dedicated process control modules, because the real transistors are too small to achieve sufficient counting statistics. The resulting graph (see Figure 1) contains the necessary information to fine tune the processing of this device.

Applications

- Concentration depth profiles of dopants in IC's, solar cells and LED's
- Metal traces at surfaces and interfaces
- Contaminants in CVD or PVD deposited thin films (Ar, Cl, O, H, …)
- Interface mixing at a film-substrate interface or within a multilayer stack
- Leaching of (earth) alkali metals from glass

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Characteristics

Sample type
- bulk solids
- thin films
- conductive or insulating

Maximum depth
- ~50 µm

Depth resolution
- 1–10 nm

Analyzed area
- 250x250 µm², down to a few µm²

Quantitative
- yes, using standards

Accuracy
- 10% (concentration)
- 3% (depth)

Elements
- H to U

Detection limit
element/matrix dependent, e.g.
- ppb for B in Si
- ppb for As in Si
- 1-10 ppm for O in Si

Destructive
- large wafers have to be broken before analysis
- the analyzed sample has a small crater of ~0.25 mm in diameter

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