Making Silicon Sensors fit for Series Production

Process Quality Control for Large-Scale Silicon Sensor Productions

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How do we automatize process quality control? – The flute concept

Test structure flutes can be tested with one system for the entire production

In just a few years, silicon sensors for tracking and calorimetry applications in HL-LHC experiments will enter the series production stage. The quality of the production process is monitored on test structures. They provide the input for simulations and valuable feedback for the sensor development process. To facilitate automatization, we group test structures around "flutes" that can be contacted with the same 20-needle probe card as at the manufacturer. The flutes form sets dedicated to extract specific process parameters. Test structures such as diodes, gated diodes, metal-oxide-semiconductor (MOS) structures, Van-der-Pauw structures, arrays of field effect transistors (FETs), bulk resistivity test structures, etc. are contained in flutes. These flutes are distributed around the manufacturing wafer and can all be tested with the same automated measurement system.

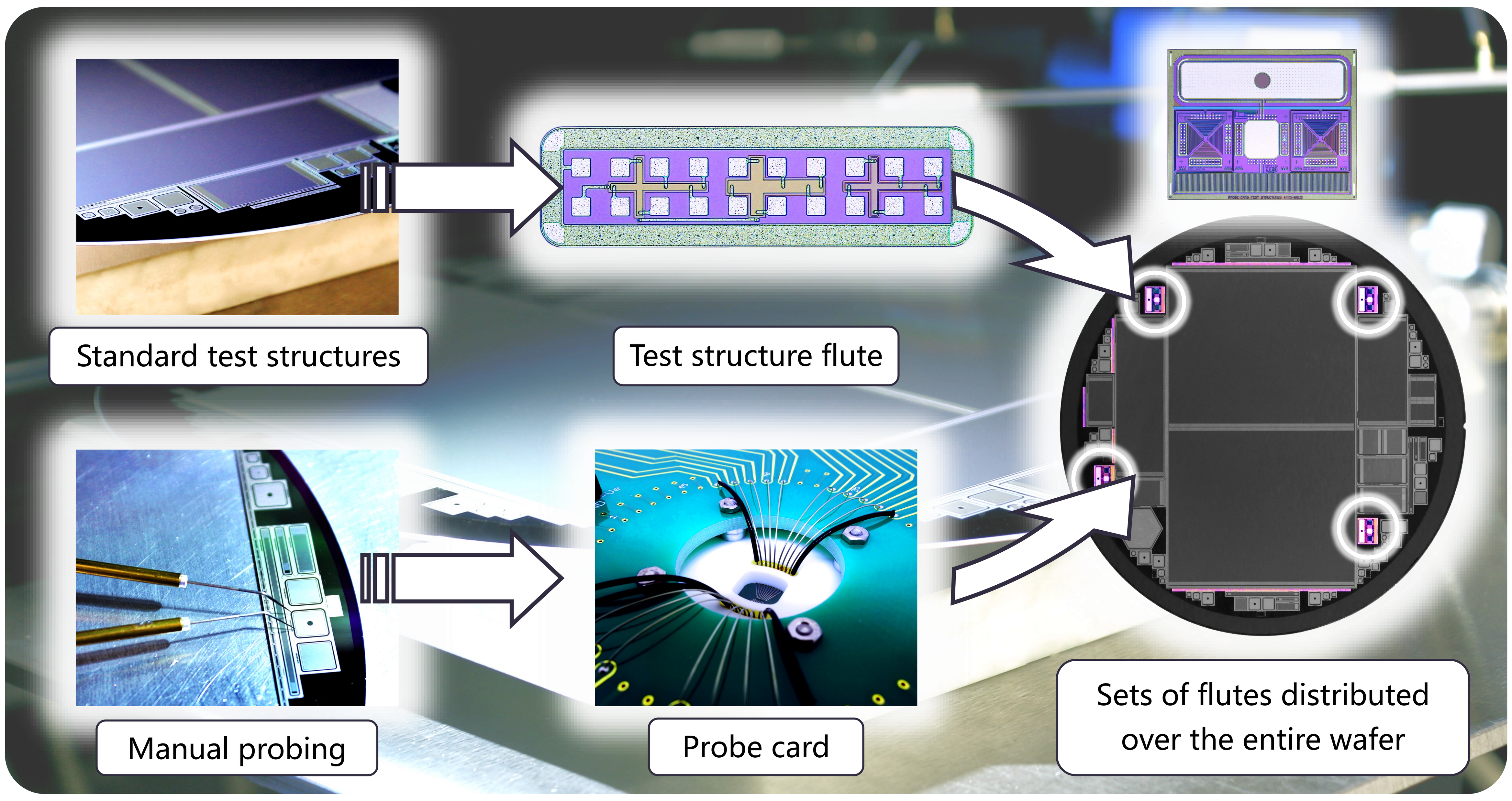

Figure 1. Automatizing process quality control. We move from manual probing on standard test structures to automated measurements with probe cards on dedicated test structure flutes all around the wafer. Like this, the whole production yield can be tested with the same method.

How do we extract relevant process parameters? – Three examples

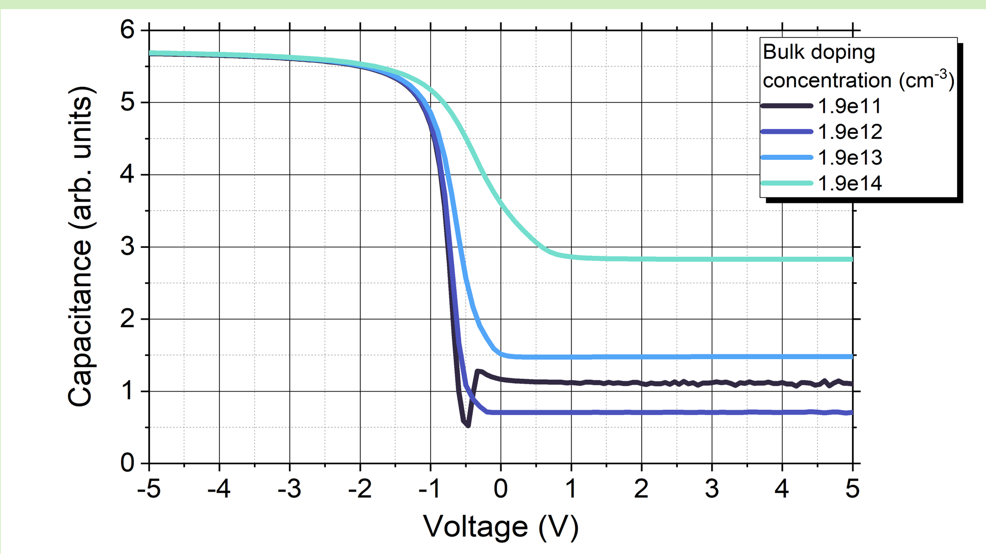

Figure 2. Synopsis TCAD simulation of MOS capacitance-voltage characteristic for different bulk doping concentrations.

Bulk doping concentration—MOS curves present alternative to diodes

In parallel to measurements, we conduct simulations to study the behavior of test structures and relate measurement data to process parameters of interest. An example of such a parameter is the bulk doping concentration or resistivity. It is typically extracted from capacitance-voltage measurements on diodes, but also MOS characteristics show a dependency on bulk doping concentration. By comparing simulations to measurement data, the doping concentration can be determined from MOS curves. It is subject of ongoing investigation whether this method could present a low-voltage alternative to measurements on diodes.

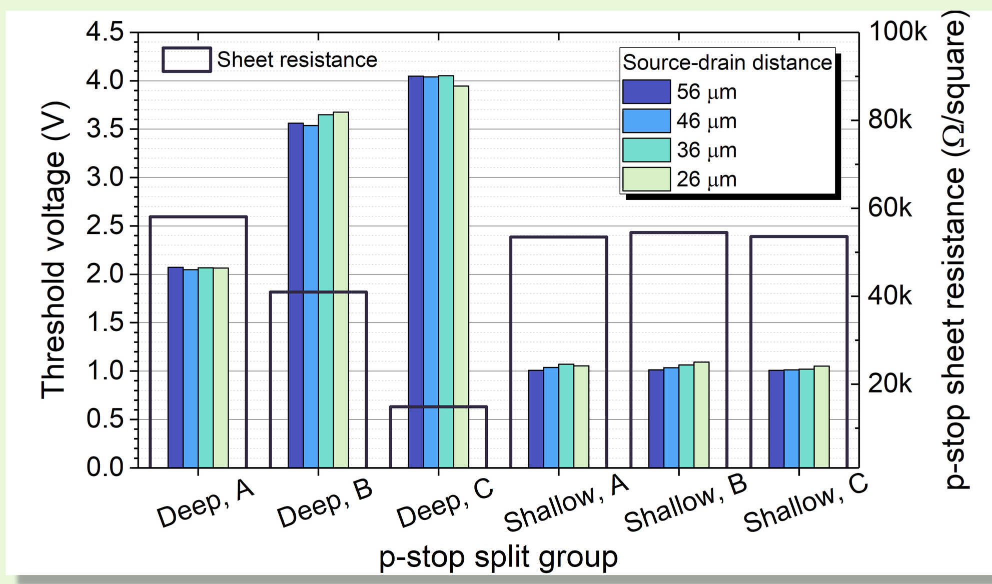

Figure 3. FET threshold voltage and p-stop sheet resistance for different p-stop concentrations and implantation depths.

Inter-strip resistance—FETs are to replace measurements on main sensors

As an alternative to strip scans on the main sensors, we investigated the capabilities of FET test structures to extract the properties of the strip-isolating p-stop layer. Both measurements and simulations found that the threshold voltage and the source-drain resistance of the FETs relate directly to the p-stop doping concentration and implantation depth. The source-drain resistance should be proportional to the inter-strip resistance of the main sensor. However, due to large measurement errors, this could not be verified yet. A new design of FETs with radial symmetry is expected to yield more reliable values of the source-drain resistance.

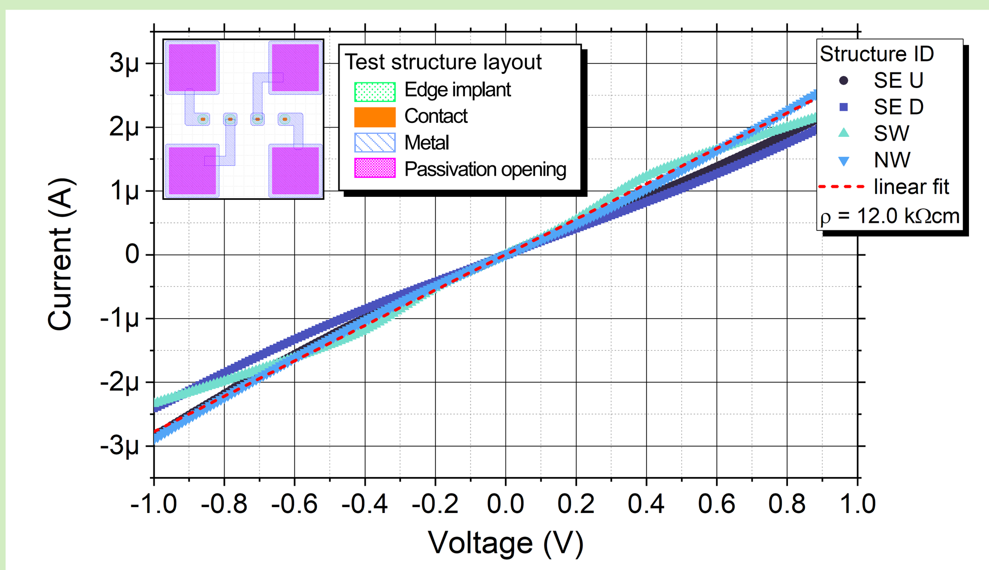

Figure 4. Bulk resistivity determined from a four-terminal current-voltage measurement on resistivity test structures.

Bulk resistivity—Alternative, smaller test structures are explored

Reducing the size of standard test structures like diodes would be beneficial for wafer design. Studies on diodes of different sizes showed that the reliability of measurements decreases with decreasing diode size. In parallel to MOS measurements, we therefore investigate the use of alternative, smaller structures to extract parameters like the bulk resistivity. As an example, we show resistivity measurements on a four-point probe test structure in the set of flutes. Currently, we are working to improve the accuracy of the method. The quality of the ohmic contact to the bulk material and the influence of surrounding structures need to be investigated.

In a nutshell

Test structure flutes allow us to monitor process quality along the entire wafer with the same automated method. A large variety of structures can be applied for quick process parameter extraction but also to provide extensive diagnostic tools to trace arising problems.

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