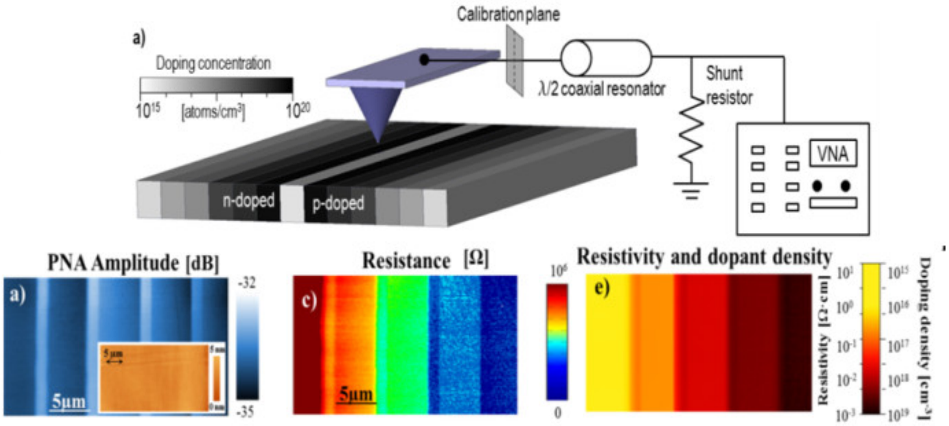
Scanning Microwave Microscopy: nanoscale imaging of material electrical properties using microwaves

In 1965 Gordon Moore estimated that the number of components on electronic chips would double every 2 years. This prediction has so far been respected. Today’s microprocessors included in our mobile phones and laptops use transistors on the chips that are only 14 billionth of a meter in length. That’s roughly 700 times smaller than a human hair! With the size of electronic chips shrinking down, there is a constant demand for new techniques that allow testing and characterizing smaller and smaller circuits. Scanning Microwave Microscopy (SMM) is a novel imaging technique that exploits the penetration capability of electromagnetic microwaves to probe material properties, with nanoscale resolution. SMM has been successfully used in different fields: from semiconductor materials and electronic devices to biological elements like individual cells and bacteria.

The SMM consists of an atomic force microscope (AFM) combined with a vector network analyser (VNA). It combines the nanoscale spatial resolution of the AFM with the broadband electrical measurement capabilities of the VNA. The operating frequency range is between 1 and 20 GHz. The field in which the SMM features have proved to offer significant benefits and insights is the electronic industry. In this context, dopant density and resistivity are two of the most important quantities monitored by the chip manufacturers. SMM allows non-invasive probing of these properties. This represents a major benefit for semiconductor industry applications, particularly in failure analysis processes. In order to extract information on material specific properties, the measured microwave signal needs to be calibrated and converted into a physical quantity. We recently developed a calibration workflow that allows obtaining complex impedance, capacitance, and resistance from the measured microwave signal. In this work we show how from the measured resistance one can gather insights on surface localized physical properties like dopant density and resistivity, with nanoscale spatial resolution. The method described in our manuscript is very easy to apply, and has the big advantage of not requiring any simulation tool to extract the physical quantities of interest.



In our study, we tested the method we developed on two silicon samples with known characteristics. The SMM resistivity and doping concentration directly derived from the calibrated SMM resistance show a quantitative agreement with the samples data-sheet. The method can be applied to extract resistivity and doping concentration of any silicon sample or device with unknown characteristics. Furthermore, the broadband capabilities of SMM can be exploited to vary the depth of the probed volume by changing the applied GHz frequency. In this way, frequency dependent depth profiling can be realized.

Publication

Probing resistivity and doping concentration of semiconductors at the nanoscale using scanning microwave microscopy.
Brinciotti E, Gramse G, Hommel S, Schweinboeck T, Altes A, Fenner MA, Smoliner J, Kasper M, Badino G, Tuca SS, Kienberger F
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