Assessing the Other Dimension in Atomically Precise Fabrication

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Patterning of hydrogen resist on silicon by scanning tunneling microscope (STM) is acknowledged as being atomically precise, in all three dimensions. Definition of electrical devices requires subsequent incorporation of dopants, not just into the pattern or into the exposed surface, but into a substitutional impurity state where all bonds are fulfilled. Electrical activation can be achieved by silicon growth around the dopants in the form of a capping layer. Unfortunately, even thin caps of a few monolayers degrade the resolution of the STM and make quantitative analysis difficult, particularly in the Z dimension.

A legitimate question then becomes: “How well can the diffusion of a single atomic layer of dopants be resolved?” Secondary ion mass spectrometry (SIMS) can achieve nanoscale resolution when optimized. Advanced modes of transmission electron microscopy (TEM) approach 1 nm resolution for chemical identification. But neither SIMS nor TEM indicate if the dopants are electrically active. Observation of weak localization in electrical transport measurements enables extraction of sub-nanometer delta-layer thickness but is challenging to perform.

Here we demonstrate the first use of infrared variable angle spectroscopic ellipsometry (IR-VASE) to characterize the atomic precision of delta-layer depth. The method is user-friendly, non-destructive, applicable at room temperature, and enables extraction of parameters that typically require multiple techniques. This work not only lays the foundation for optimized processing, but also provides characterization of these novel structures in the mid-IR.

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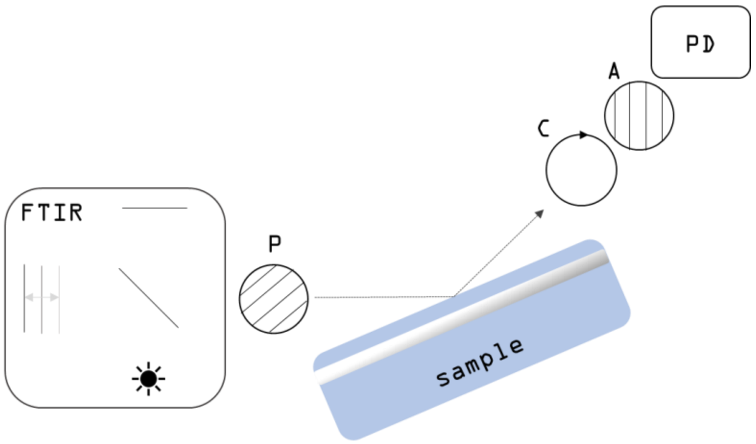

Figure 1: Schematic representation of IR ellipsometry measurement. Light from a FTIR illumination source is polarized by a wire grid polarizer (P), reflected by the sample, traverses a rotating compensator (C), wire grid analyzer (A) and is collected by a photodetector (PD).

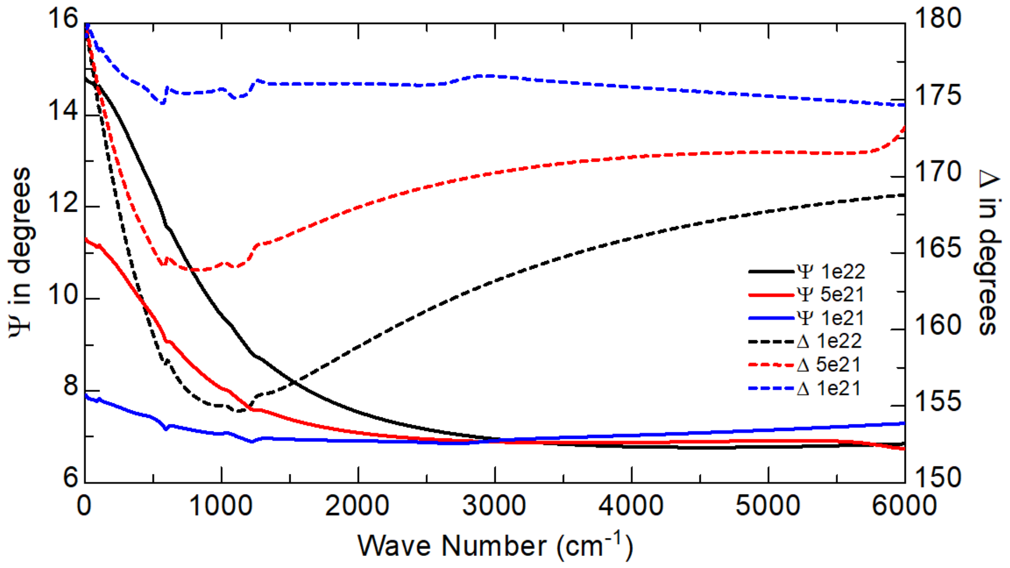

Figure 2: Calculated ellipsometric spectra for a 1 nm thick delta-layer embedded in silicon with a 3 nm surface oxide as a function of carrier concentration (10^{21} to10^{22} cm^{-3}). Despite being extremely thin, the high delta-layer carrier concentration leads to identifiable signatures at mid-IR wavelengths.