Abstract No. jord0544

In-Situ Monitoring of Thin Film Reactions During Rapid Thermal Annealing: Nickel Silicide Formation

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Beamline(s): X20C

Introduction: Silicides are used as low resistance electrical contacts to the source, gate, and drain in CMOS field-effect transistors. As devices get smaller, more restrictions are placed on the materials used for making the silicides. Nickel silicide is a candidate for contacts in future generations of transistors. It is important to understand the phase transformations and properties of phases in the Ni-Si system in order to determine the optimal recipie for making good low resistivity and thermally stable contacts. We demonstrate that multiple metal-rich phases are present in the Ni-Si system when reacting a thin Ni film with an underlying Si substrate. The formation temperatures for the metal-rich phases are highly dependent on dopant type and surface preparation. We also show that a serious limitation for NiSi implementation in devices is the low morphological stability of the film which degrades before the monosilicide transforms to the high resistivity $NiSi_2$ phase.

Methods and Materials: We have used a combination of *in-situ* monitoring techniques during rapid thermal annealing of thin films to follow changes in phases, texture, resistivity, and surface roughness as reactions occur. The characterization apparatus combines time-resolved diffraction, elastic light scattering, and resistivity measurements. Using a position-sensitive detector, diffraction spectra can be taken every 100 ms where x-ray peaks are sequentially observed during annealing, allowing for phase identification and determination of phase transformation temperatures. Optical scattering is simultaneously measured using HeNe laser light coupled in and out of the annealing chamber with fiber optics. The resistance is measured using a four-point probe.

Results: A typical example of the reaction of a 10 nm Ni film deposited on an n-doped polySi substrate is shown in Fig. 1. The x-ray intensity is presented as a color scale and as contours (1b). The presence of the metal-rich phases between 250 ^{o}C and 400 ^{o}C is clear not only in the x-ray diffraction spectra but also in the variations measured in the resistance. Slightly below 400 ^{o}C, the 5 μm light scattering signal increases significantly. This increase can be correlated with either surface pits appearing as NiSi starts to form or could also be related to the reported low temperature formation of $NiSi_2$ inverted pyramids. The large roughening observed with both light scattering signals above 600 ^{o}C occurs at least 100 ^{o}C below the temperature at which the high-resistivity $NiSi_2$ forms. This suggests the agglomeration of the thin NiSi films precedes the disilicide formation. The higher temperature disappearance of the $NiSi_2$ x-ray peak slightly below 1000 ^{o}C was observed with every Ni film and is related to the partial melting of the silicide and possible texturing in the layer. Fig. 2 shows the influence of dopant type on the formation of metal-rich silicide phases. There can be temperature variations of more than 50 ^{o}C at 350 ^{o}C.

References: C. Lavoie, R. Purtell, C. Coïa, C/. Detavernier, P. Desjardins, J. Jordan-Sweet, C. Cabral, Jr., F.M. d'Heurle, J.M.E. Harper, Electrochem. Soc. Proc. **2002-11**, 455-467 (2002).

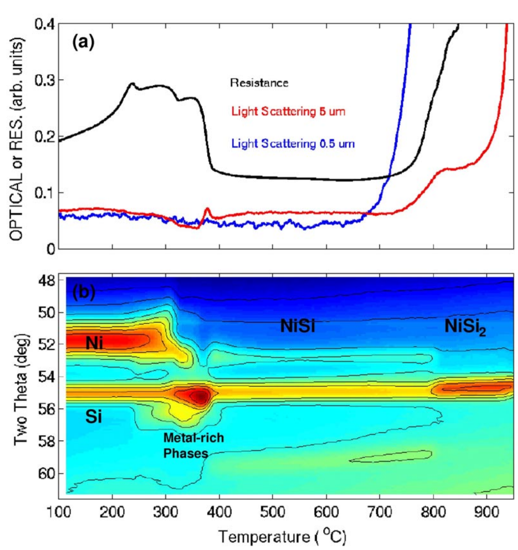

Fig.1 (a) resistance and light scattering from 0.5 and 5 μm length scales and (b) x-ray diffraction during 3^{o}C/s anneal.

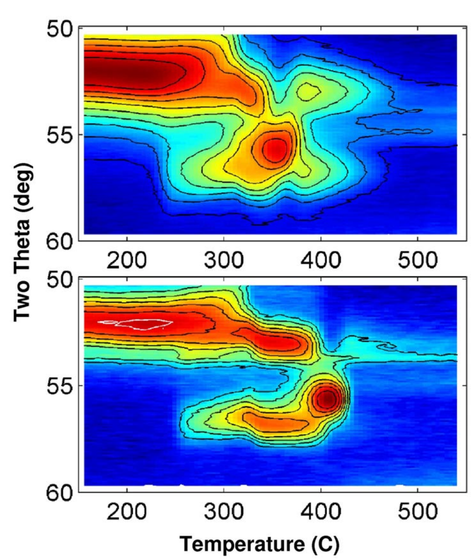

Fig.2 X-ray measurement during annealing of a 10 nm Ni film on (a) n-doped and (b) p-doped SOI.