Neutron Reflectivity

applied to delamination studies in microelectronics

NANOELEC. ADVANCED CHARACTERISATION PLATFORM GRENOBLE

NEUTRONS FOR SCIENCE®

Neutron Reflectivity (NR) is powerful non-destructive tool for the characterisation of multi-layers, surfaces and interfaces used in microelectronics. It allows the measurement of interfacial properties and thin-film thicknesses with very high resolution. The use of neutrons provides unique capabilities for the study of light elements and for the characterisation of buried interfaces.

Context

The fabrication of integrated circuits (ICs) in the microelectronics industry frequently involves multilayer structures with stacked materials (metals and dielectrics) on a silicon substrate. The variety of these materials and the number of sequential processes make the reliability of these multilayer stacks a major concern. Delamination at a particular interface is a serious problem, not only due to the loss of the wafer itself but mainly from the equipment downtime in manufacturing. The semiconductor industry is continuously seeking solutions to minimise delamination risks well in advance of full-scale IC manufacture.

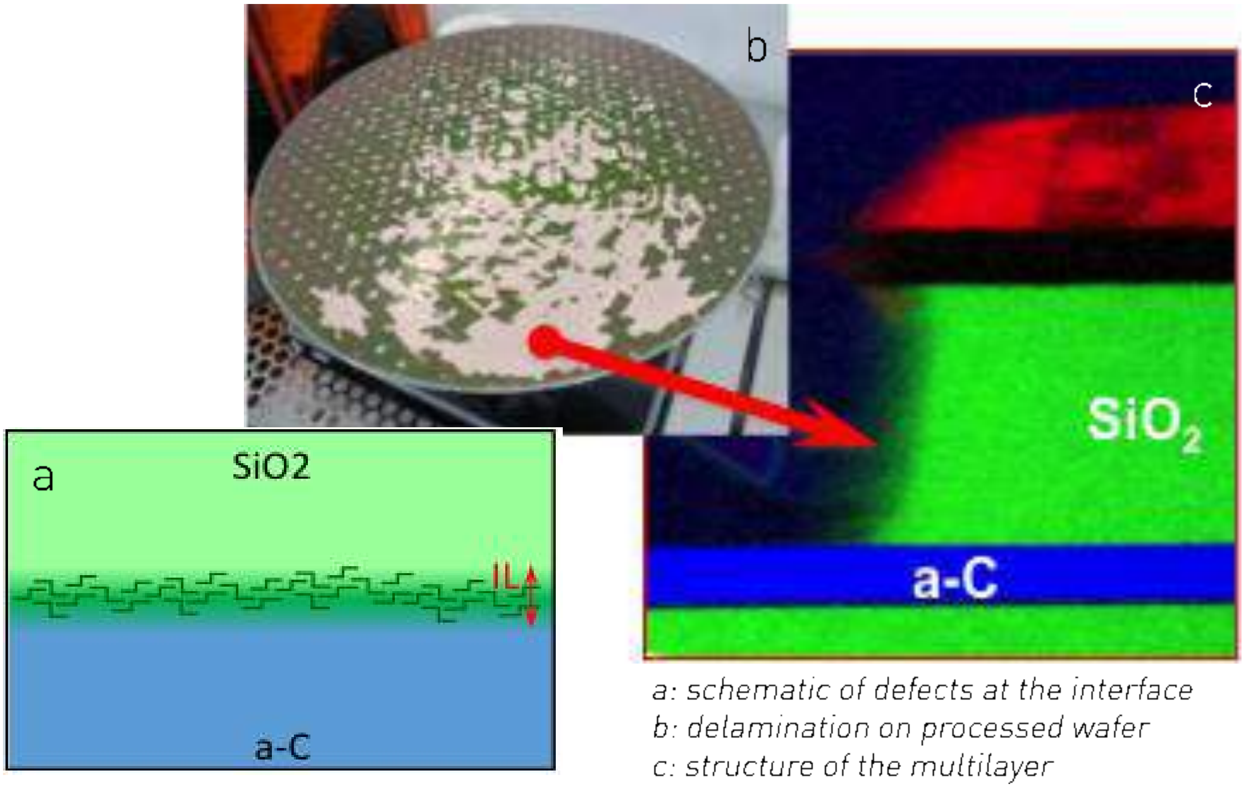
The challenge

The main objective of this study is to develop a method to anticipate the risk of delamination of a given interface well before the IC manufacture. It would be desirable to predict the risk of delamination not only qualitatively, but also quantitatively. To do this, the underlying mechanism behind the delamination has to be identified and fully characterised, in order to relate one or several of its characteristics to the risk of delamination. This would in turn allow to accurately understand and predict the risk of delamination before of full-scale IC manufacture, allowing it to be mitigated and ultimately increasing yield.

The results

At the Institut Laue-Langevin (ILL) neutron reflectivity was used to characterise the interface between amorphous carbon (a-C) and SiO2. Two different deposition conditions used to grow a SiO2 layer on top of a-C were tested. XRR was unable to detect any difference between the two samples. NR results, however, showed the presence of an extra layer between the a-C and the SiO2. This intermediate layer (IL) reveals the presence of hydrogen. Furthermore, the thickness and H-concentration of this IL differ for the two samples. The appearance of non-specular signal in the NR data of the sample with the weakest interface indicates the existence of a microstructure associated with the delamination.

Combined NR and complementary XRR measurements unambiguously determine the chemical composition of the structure as a function of depth. NR measurements were performed on the D17 reflectometer at ILL and XRR measurements at the nanocharacterisation platform (PFNC) at the Minatec Campus in Grenoble, using a commercial X-ray bench. [J.Segura-Ruiz et al. Journal of Applied Physics 117, 215302 (2015); https://doi.org/10.1063/1.4921865].



a: schematic of defects at the interface
b: delamination on processed wafer
c: structure of the multilayer

Conclusion

Combined NR and XRR characterisation of the a-C/SiO_2 interface showed that the weakness of this interface is related to the accumulation of hydrogen at the interface. The weakness is more important for a thinner IL with a higher H-concentration. H-concentration and thickness of the IL seem to be correlated with a greater susceptibility of cracking in the vicinity of this interface, consistent with the appearance of off-specular scattering. This discovery should allow the risk of delamination to be anticipated and quantified. The H-accumulation could take place in other interfaces of interest for microelectronics, broadening the application of this technique.

The technique

- Neutron Reflectivity involves reflecting a well-collimated neutron beam from a surface and measuring its fraction as a function of wave vector transfer. The thickness, roughness and density of material as a function of depth can then be accurately modelled.
- Neutrons are highly penetrative, but most importantly are very sensitive to the presence of hydrogen. X-rays only measure the electron density regardless of the elemental composition, so light elements such as hydrogen are particularly challenging to detect.
- NR is a suitable technique whenever hydrogen, widely used in deposition techniques in microelectronics industry, is involved, either in delamination studies or in other reliability mechanisms.

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