Platform for Advanced
Characterisation | PAC-G

Transmission X-ray reflectometry for **wafer bond characterisation**

X-ray reflectometry in transmission mode is a very effective technique giving information on the thickness, the electronic density and the roughness of bonded wafers and buried interfaces. This technique is able to probe extremely thin bonding layers (several Å to 1nm) between two substrates with sub-Å precision.

Context

3D integration technologies have been widely adopted in semiconductor industries, specially in the sensor and memory markets. One of the building blocks of 3D integration consists in bonding together two patterned wafers (or dies), without using any adhesive or additional material (direct bonding). Molecular Van der Waals forces keep the two wafers together. However, the bonding layer must respect several strict requirements in order to meet expected device performance and reliability. The in-depth characterisation of these bonded layers is then of crucial importance in order to ensure devices work properly as designed.

The challenge

Bonding layers are typically in the range of several Å to 1 nm of thickness and consist mostly of air or water, that have low electron density. They are also buried between two thick and large substrates, making them very difficult to probe. Sample preparation of these Å-thin layers is also very challenging as it can alter their state, making the use of conventional lab techniques very hard. **Synchrotron X-ray reflectometry** provides statistical, non destructive and very accurate measurements, even from low electron density layers. The high-energy and high brilliance X-ray beam passes through the wafers and is small enough to look at the bonding layer.

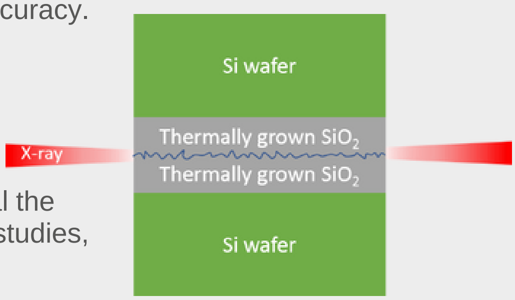
The results

The extremely high brilliance synchrotron light available at the ESRF made it possible to perform X-ray reflectometry measurements in transmission mode. Very high photon flux provide enough signal even from extremely low electron density and very thin layers as the ones found in bonded wafers. Bonding parameters were measured with very high precision (sub-Å) and accuracy.

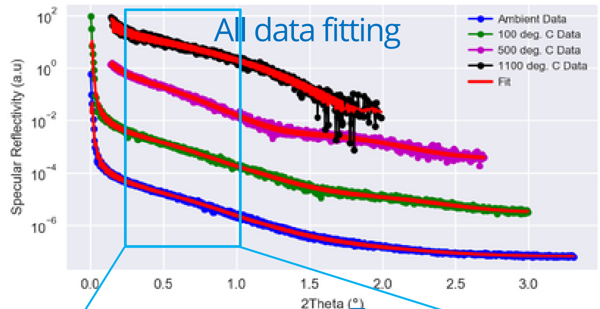
Bonding layer's parameters measured by XRR:

- Layer thickness
- Layer roughness (σ RMS)
- Layer electronic density

These results are in perfect correlation with literature and reveal the power of synchrotron X-rays for applications such as reliability studies, process development and yield enhancement.



a)



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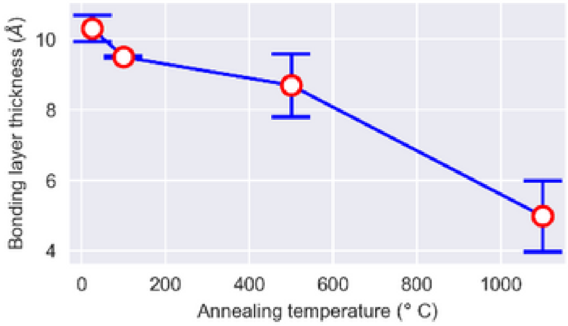

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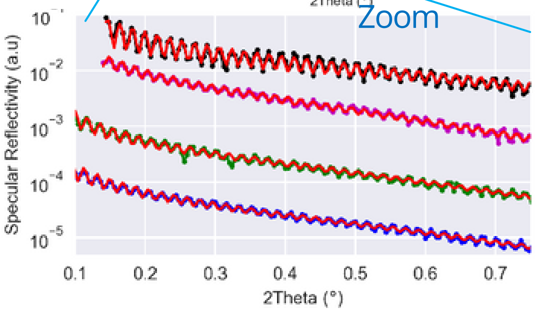

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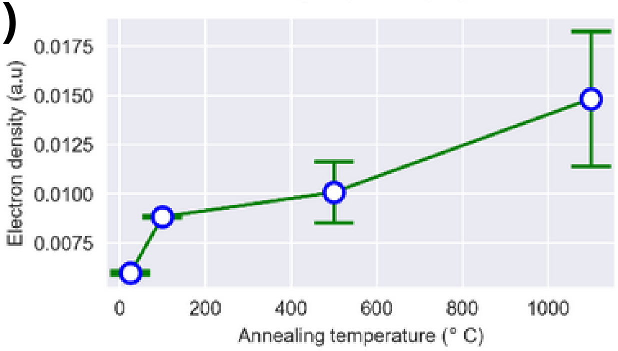
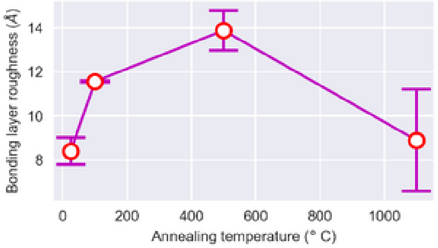


e)



Conclusion

The signature coming from the bonding layer is unequivocally defined. Data are fitted with a model (Fig a) and c) above), providing valuable and accurate information on the thickness of the bonding layer, on its electron density and on its roughness (see Fig. **b)**, **d)** and **e)** above, respectively).
The thickness and electron density of bonding layer are then studied as a function of the annealing temperature. The results show that the bonding layer is closing with the annealing temperature, along side with an increase of layer's roughness and electronic density. This results are in complete agreement with theory and previous studies and can be used in the elucidation of delaminations and other reliability issues as well as in the development of new bonding processes.

The technique

- A very powerful X-ray beam, focused down to micrometre scale, highly parallel and at high energy (above 25 keV) passes through the bonding sample (several millimetres width) at very low attacking angle.
- The scattered beam exits the sample from the opposite side, also at low angles.
- A high-Z 2D detector (CdTe sensor, highly efficient at high energy) is placed behind the sample and collect scattering data.
- Specular and off-specular scattering data are recorded simultaneously thanks to the 2D detector, reducing the acquisition time and cost of the measurement.
- The energy-selective 2D detector helps reducing the background noise, thus enhancing data quality.