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Application note from the Spectroscopy Products Division

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Imaging of silicon stress in microelectronics using Raman spectroscopy

Measuring silicon stress

A key issue for the ever-evolving world of microelectronics is to find solutions for controlling the miniaturisation of integrated circuits. One of the principal hurdles to overcome is the strain-induced failure arising from lattice mismatch among different materials, different thermal expansion coefficients, sharp patterning, and device re-scaling. Raman microscopy is the most effective tool to monitor quickly and non-destructively the formation and evolution of stress throughout all steps of production.[1,2,3]

The method is to monitor the sharp and intense Raman band of the silicon substrate throughout the sample. The energy of this band corresponds to the collective vibration energy of the Si atoms in the substrate. When the crystal is strained, the energy of vibration changes, and the Raman band is shifted to either higher (compression) or lower (expansion) energy. For example, a compressive hydrostatic stress of 100 MPa causes a band shift of 0.5 cm^{-1}.

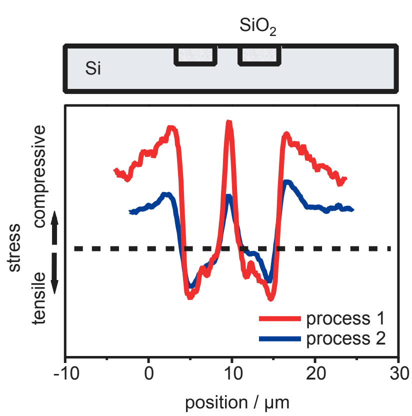


Figure 1. Stress variations across a Si-SiO_2 pattern produced using two different processes.

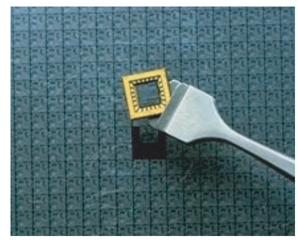
Raman spectroscopy has undoubted advantages over other techniques. Firstly, the high spatial resolution in point imaging is unrivalled (spatial features as small as 0.2 μm can be distinguished with Renishaw's instruments). Secondly, it is non-invasive (the stress measurement is a true measure of the stress of the sample, not the stress induced by sample preparation). Thirdly, it allows fast analysis that can be employed in academic and commercial research as well as in production lines.

Renishaw's Raman microscopes can aid the identification of the process step that causes device failure, or the optimum treatment temperature required to minimise the system's stress.

Image silicon stress quickly and easily…

…in the lab

…on the production line



Renishaw's inVia Raman microscope with Class 1 laser safe enclosure

Renishaw plc

Spectroscopy Products Division
Old Town, Wotton-under-Edge,
Gloucestershire GL12 7DW
United Kingdom

T +44 (0) 1453 844302
F +44 (0) 1453 844236
E raman@renishaw.com

www.renishaw.com

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Raman used to monitor stress in microelectronics

A recent study, undertaken by Bonera *et al.* of Laboratorio MDM (Italian Institute for the Physics of Matter), sought to image changes in silicon stress caused by common processing techniques in microelectronics.

Figure 1 shows typical Raman microscopy results. After several trials, with the help of Raman spectroscopy, the stress generated in the silicon devices during processing was halved. A new process was developed that produced a less strained and better working device, which has obvious financial implications. Noteworthy is the possibility of monitoring the stress in the substrate even after transparent or semi-transparent films have been deposited on the original Si substrate. This method is also useful in characterising many of the most commonly used surface coatings in microelectronics. The short timescale of approximately a minute to acquire line-scans ensures the sample is available to undergo further analysis, or to continue the production process with minimal disruption.

The effects of the complex geometry of real circuits are also worth considering here. Corners and sharp structures unpredictably affect the stress topography on a sub-micrometre scale. The high stability (due to the rigidity of the honeycomb mounting plate and Renishaw's patented kinematic mountings) and efficiency of Renishaw's spectrometer allows acquisition of detailed images like the M-shaped oxide pattern (Shallow Trench Isolation - STI) shown in Figure 2. Black tensile stress spots can be seen at the outer corners of the structure, and red compressive stress spots at the centre.

This trial has demonstrated how Raman spectroscopy is the ideal tool for the detection, monitoring and imaging of stress and strain in Si-based microelectronic components. All the data were collected using Renishaw's Raman microscope equipped with an encoded motorised XYZ sample stage. The high stability, sensitivity and repeatability of Renishaw's Raman systems is particularly suited to applications of this kind.

All data courtesy of E Bonera, Laboratorio MDM, Italy.

References:

1. Bonera E, Fanciulli M, Batchelder DN; Appl. Spec. (2002) 56, 560.

2. Bonera E, Fanciulli M, Batchelder DN; Appl. Phys. Lett. (2002) 81, 3377.

3. Bonera E, Fanciulli M, Batchelder DN; J. Appl. Phys. (2003) 94, 2729.

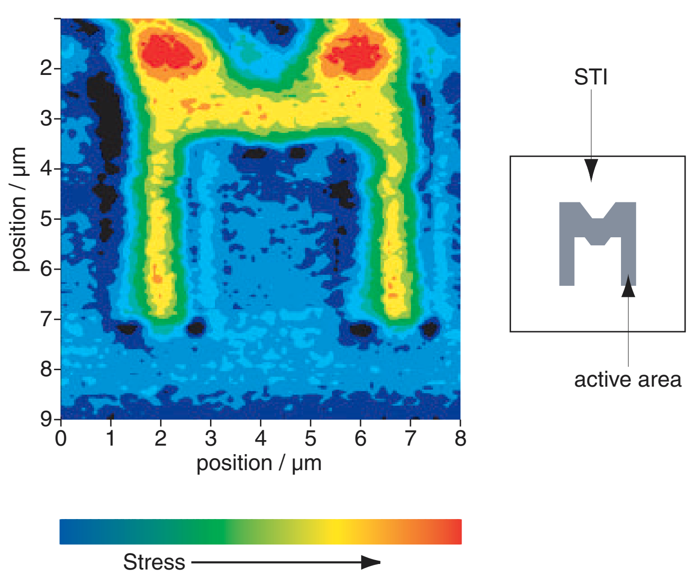

Figure 2. An M-shaped shallow isolation trench generates a complex stress distribution, which can be imaged using Raman spectroscopy.