Nanometrology: enabling applications of nanotechnology*

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The practical application of nanotechnology, in terms of large scale production of nano-functional devices and materials, requires the development of suitable nanometrology techniques, which are tailored to (a) the features of the fabrication techniques used and (b) the parameters of the structures to be realised. After a general introduction to nanometrology, we discuss metrology techniques developed to meet the requirements of two emerging alternative patterning methods, nanoimprint lithography (NIL) and self-assembly of particles. The use of photonic and photo-acoustic effects as the basis of these metrologies ensures that they are non-contact, non-destructive and relatively quick to use.

Nanoimprint lithography (NIL) is an alternative high resolution, relatively low cost, lithography method for fabricating structures with features as small as ten nanometres, on silicon wafers up to 300 mm diameter. Sub-wavelength diffraction metrology is a new technique which has been used to characterise structures with critical dimensions as small as 50 nm, to distinguish defects [1] produced during the nanoimprint process. It is suitable for use in either inline or in situ configurations, as it requires no spectroscopic or goniometric scanning. The technique analyses a single diffraction pattern image from specially designed grating test structures, and based on the relative diffraction intensities, information can be obtained about the critical dimension, height and presence of defects in the structures. Measurements performed on a series of gratings with gradually increasing line-widths show that sensitivity to dimensional changes of at least +/- 5 nm.

Photoacoustic metrology has been used to characterize the dimensions and physical properties of polymers used in NIL. The Young's modulus of layers of PMMA and the resist mr-I 6000, of thicknesses from 586 to 13 nm, have been measured [2,3]. Acoustic phonons are generated by a 70 fs laser pulse in a pump-probe configuration (Fig. 2a). Back-scattered acoustic waves are detected at the sample surface via the change in reflectivity (Fig. 2b), and a delay line on the pump beam enables temporal resolution of 0.1 ps, with depth resolution of 10 nm. Physical parameters determine the stability of polymer nanostructures and dictate the optimum temperature, pressure and time required for NIL. Photoacoustic metrology has been used to demonstrate an increase in acoustic speed, and correspondingly Young's modulus for PMMA samples thinner than 80 nm (Fig. 2c) [3]. We are currently studying Young's modulus as a function of temperature, approaching the glass transition temperature.

Self-assembly is an emerging and highly versatile approach to nanofabrication. However, perfect crystallographic order in the plane is seldom possible. We have developed a way to obtain improved crystal ordering in the plane and in the bulk by applying acoustic fields during vertical drawing crystallisation of colloidal mesoscopic and nanoparticles [4]. The degree of crystallinity is quantitatively measured using discrete Fourier Transform analysis of the scanning electron micrograph or AFM images [5]. This approach can be extended to quantify ordering of other self-organised structures, such as micells or self-organised quantum dots. Our study covered also the 3-dimensional ordering of these structures by transmission spectroscopy [5].

We have demonstrated new methods to characterize the structures produced by nanoimprint lithography and self-assembly, bringing these techniques closer to standardized measurements, which is a prerequisite for uptake in future applications.

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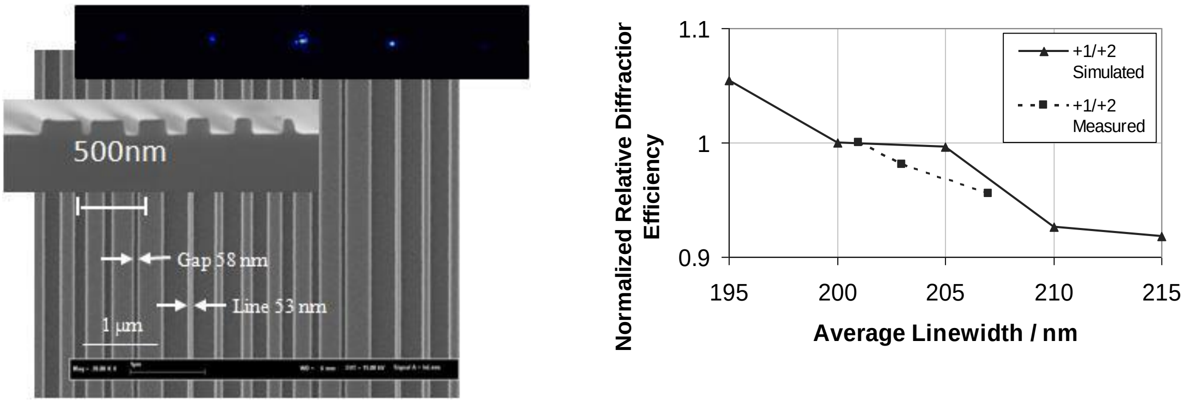
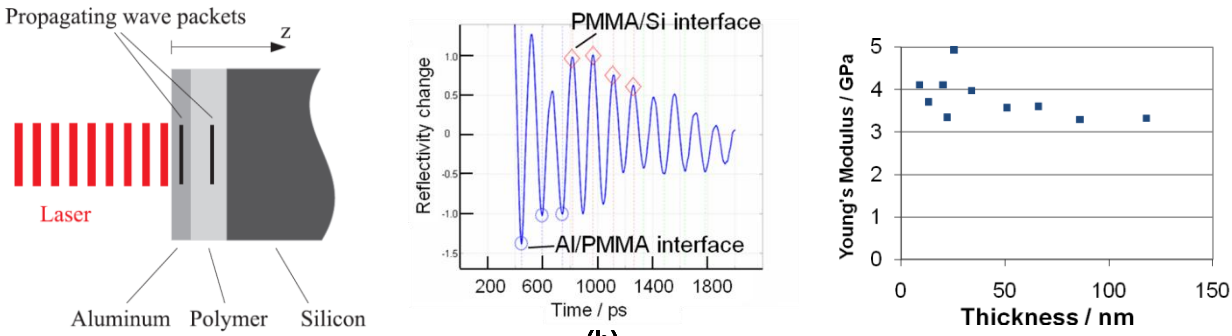


(a)

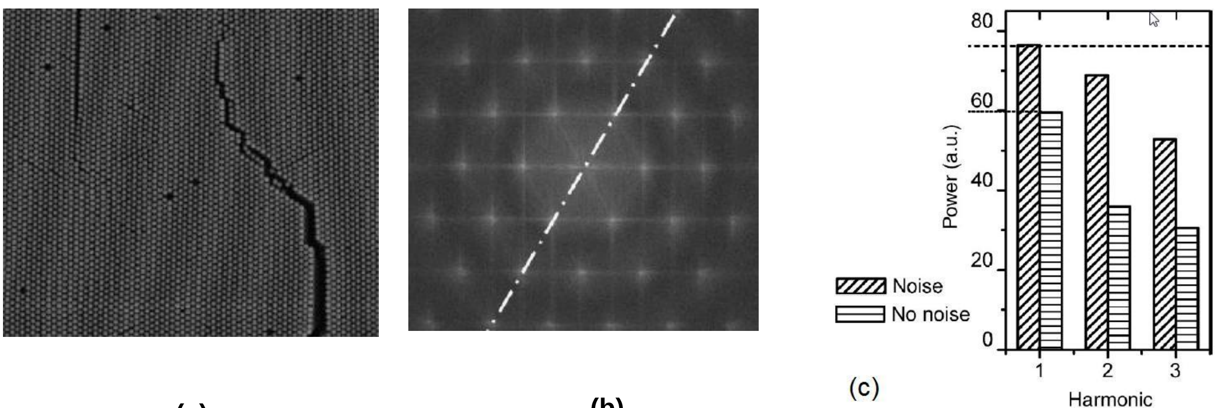
(b)

Figure 1. (a) Test gratings stamp and imprint (inset); Diffraction pattern (inset); (b) Measured and simulated relative diffraction efficiency of first and second orders, as a function of average grating linewidth



(a) (b) (c)

Fig. 2. (a) Schematic diagram of the photoacoustic process. (b) Photoacoustic data from 51 nm thick polymer sample, showing signal from interfaces. (c) Young's modulus measured as a function of sample thickness.



(a) (b)

Fig. 3. (a) SEM image of opal film; (b) Fourier transform (FT) pattern of the SEM image; (c) Magnitudes of the first three FT harmonics, showing improvement in order due to noise