Whitepaper

Sub-nm layer measurements using ASOPS and laser induced ultrasound

***Abstract**: The measurement of thin film layer thickness in industries such as silicon wafer manufacture requires the highest accuracy, resolution and speed, all in a non-invasive, non-destructive method. Here we report on laser-induced ultrasound using two frequency offset high repetition rate lasers to study layer thickness to a sub-nm resolution.*

Thin films and microstructures are widely used in many technologies throughout science and industry; testing their mechanical properties is essential to maintain their performance. There are many methods currently available for non-invasive testing of properties such as surface roughness and optical or electrical behaviour. Mechanical properties such as layer thickness and visco-elastic behaviour are more difficult to achieve non-destructively at high resolution and accuracy.

Laser induced ultrasound generation and detection in a pump probe system is shown here to offer high resolution (sub-nm) in measurements of layer thickness of multi-layer samples. Additionally, information on sound velocity, elastic modulus and interface delamination can be obtained.

This report details an ultrasonic spectroscopy technique using two synchronised Ti:Sapphire mode-locked lasers as pump and probe sources. The pump laser induces a picosecond strain pulse which propagates into the sample with a longitudinal sound velocity and is then partially reflected or diffracted as it encounters interfaces or inhomogeneities. On reaching the surface, the reflected pulse induces a change in reflectivity which can be detected by the probe laser pulse. By varying the time delay between pump and probe pulse, depth resolved information is obtained (Fig. 1). Lateral information can be obtained by scanning across the sample and the resolution can be adjusted via the spot size from 1μm to 100μm, enabling imaging of the layer. Additionally, by fibre coupling the system, measurements can be made

Fig. 2: The **taccor** 1GHz repetition rate laser.

with the sample in-situ for in-process quality control testing.

The technique of off-setting the repetition rate frequency of two mode-locked lasers, known as ASynchronous OPtical Sampling (ASOPS), gradually increases the time delay between pump and probe pulses without the use of mechanical delay lines. When used with the high repetition rate (1GHz) **taccor** (Fig. 2) sub-nm resolution at kHz scan rates can be achieved.

The time span for a single ASOPS measurement corresponds to the inverse of repetition rate difference, typically ~100μs. The kHz scan rates result in shot noise limited measurements and with one second of signal averaging, signal to noise ratios of 107 can be achieved with a time resolution of 50fs.

To demonstrate the applications of ASOPS ultrasound spectroscopy N. Krauß, A. Nast, D.C Heinecke and T. Dekorsy[1], University of Konstanz, Germany, carried out a layer thickness inspection of a silicon/molybdenum (Si/Mo) Bragg mirror, commonly used for lithography in the extreme ultraviolet (EUV) region. Due to the short wavelengths used in lithography, the layer thickness of these mirrors need to meet sub-nm precision. The mirror used by the team had 60 Si/Mo layers with a superlattice period of 6.8nm totalling a layer thickness of 408nm.

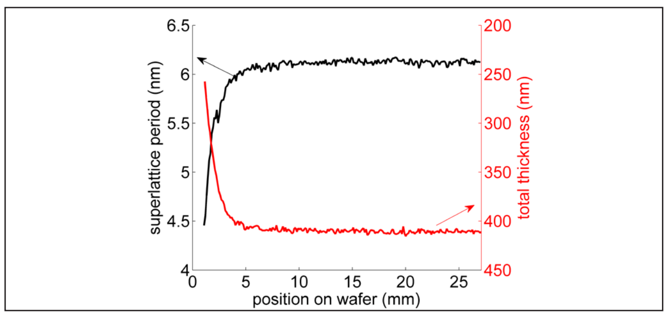

Fig. 4. The superlattice period and total superlattice thickness of the Si/Mo mirror with respect to the distance from the wafer edge. Results show layer thickness decrease at the mirror edge.

The pump laser at time zero caused a rise in reflectivity at the surface followed by an exponential decay with a time constant of several picoseconds. At later times, echoes from the layer stack and a reflection off the substrate return to the surface and cause modulations of the sample reflectivity (Fig. 3). If the average longitudinal sound velocity of the Si/Mo is known, this ultrasonic measurement directly gives the superlattice period and the total thickness of the Bragg mirror. Due to uncertainty in the sound velocity in their sample, the team from the University of Konstanz were unable to report exact thickness but were able to demonstrate thickness deviations along the mirror with a level of accuracy better than 1%. In their studies, they found the mirror centre had a standard deviation in the superlattice period of less than 0.1nm, but towards the wafer edge, a decrease in the thickness was seen due to inhomogeneities in layer growth (Fig. 4 & 5).

Laser induced ultrasound is a well-established test method used in science and industry but using two Ti:Sapphire 1GHz **taccor** lasers from Laser Quantum, together with the **TL-1000-ASOPS** repetition rate offset unit to control the pulse trains, the team from University of Konstanz demonstrated the ability to obtain far higher resolutions at higher scan speeds.

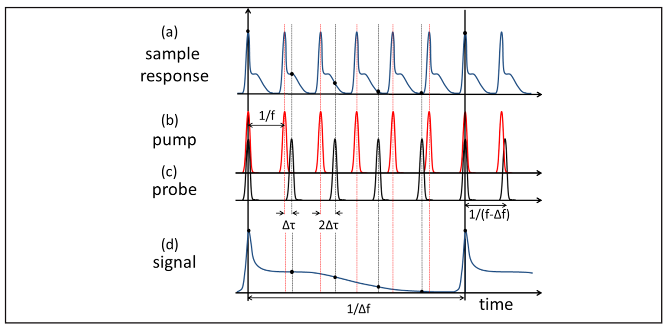

Fig. 1: (a) Actual sample response. (b) & (c) Pump and probe pulses with frequency offset gradually increasing the time gap between them. (d) The detected signal.

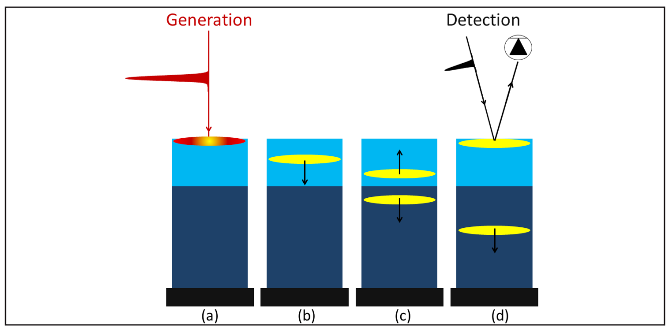

Fig. 3: (a) A pump pulse from a femtosecond mode-locked laser causes a picosecond strain pulse at the surface of the sample. This strain pulse propagates through the layer. (b) Reflecting of inhomogeneities or interfaces reflecting back to the surface. (c) The acoustic reflection can be detected at the surface by the incoming probe pulse.

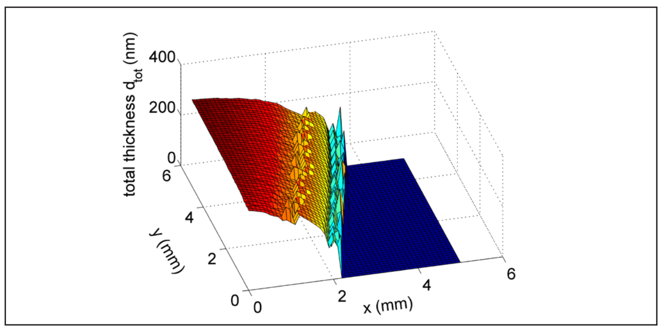

Fig. 5. The total thickness of an EUV mirror, measured with a fibre coupled ASynchronous OPtical Sampling (ASOPS) system. The image consists of 50x50 pixels per 0.1mm.

Acknowledgements:

[1]"Laser –induced ultrasound for applications in metrology" N.Krauß et al. Laser+Photonics January 2015 Pg 74-76.

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