Spatially resolved determination of stress in thin films and substrates from curvature measurements

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The residual stress is an important physical property influencing the mechanical characteristics of hard coatings, the optical properties of thin films stacks, the band structure of (opto-)electronic films, as well as functionality and reliability of electronic devices (1, 2).

The presence of mechanical stresses can affect the integrity of coatings and devices in a stabilizing or destabilizing way. At elevated temperatures film stresses and stress gradients foster and direct atom diffusion and vacancy migration, thus supporting e.g. the formation of crystallographic defects like stacking faults and promoting the occurrence of hillocks, whiskers and microcracks.

In general, depending on the films application, residual stresses may bring about beneficial as well detrimental effects. In any case, knowledge of the sign and amount of strain is important to follow up various stages of film and device processing: film deposition and annealing, lithographic structuring of layers and substrates (e.g. for MEMS), packaging of the devices.

The quantitative determination of the stress in a thin film via the measurement of the curvature of its substrate is straightforward and is routinely applied using several technical approaches (3-6).

Some techniques, which probe the geometrical surface of the curved sample (e.g. stylus profilometry, laser scanning techniques) need to assure that the local curvature actually measured is not affected too much by sample waviness stemming from the substrate. Thus, usually a differential measurement procedure involving measurements of the surface profile before and after deposition of a strained thin film is applied in order to single out the sample curvature due to mechanical film stress from unwanted substrate effects.

Other techniques rely on the presence of a perfect single crystalline substrate (e.g. X-ray diffraction techniques) because they probe the curvature of the crystal lattice planes of the substrate. This frees from problems associated with wavy or corrugated surfaces. However, certain types of crystal defects like subgrain boundaries and wafer warping may spoil the perfect flatness of lattice planes, too. In these cases a differential measurement procedure again may be needed.

In any case, the different characteristics of the measurement techniques usually demand that inherent sources of error should to be properly accounted for. This is especially true, when stress values obtained by different techniques are to be compared on an absolute scale.

During the optimization of thin film deposition processes very often homogeneity issues arise. Here, spatially resolved measurements help to find and eliminate causes of inhomogeneity. Similarily, with laterally structured films the local amount of strain in the underlying substrate is of interest. Last but not least, local stresses in thermally loaded devices limit functionality and should be measurable. All these applications ask for spatially resolved stress measurements.

In this paper we will compare the limits and some pecularities of two sample scanning techniques offering spatial resolution:

- a "revitalized" X-ray diffraction technique (5),
- stylus profilometry using mechanical or optical styli.

Emphasis will be laid on the X-ray diffraction technique which offers automated measurements on samples with high strain sensitivity (<10 MPa) and a lateral resolution which can be made to be as low as 30 µm. In particular with commercial silicon wafers a measurement prior to deposition is usually unnecessary, while the system can handle specimens with diameters ranging from 1 to 300 mm. This makes it a useful tool for routine measurements during the optimization of deposition parameters (Fig. 1).

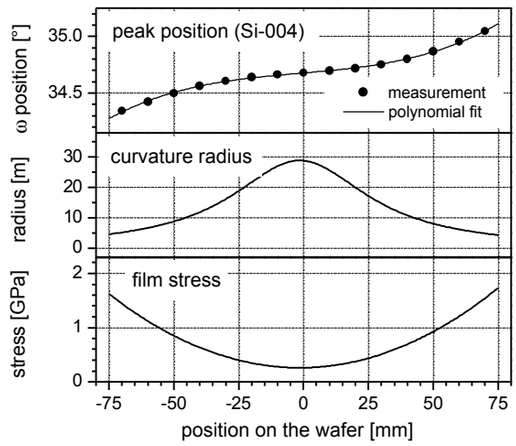

Fig. 1 X-ray curvature measurement and evaluations of a nitride film deposited by magnetron sputtering on a (100) silicon wafer of 150 mm diameter.

The X-ray technique is completely insensitive to surface morphology, e.g. corrugations. Since this non-contact technique uses penetrating radiation, it can even be applied to measure the state of strain of films and devices under thermal load and "inside" electronic packages.

Measurement geometries, evaluation techniques and applications in thin film deposition optimization and device failure analysis will be presented.

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