Microelectromechanical Thin Film Stress Sensors

Personnel

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Sponsorship

NSP and SMA

We have designed and fabricated several microelectromechanical devices for measurements of film stress during deposition and post-deposition processing.

The operation of one class of devices is based on buckling of membranes and beams. Single-crystal Si membranes can be made through patterned anisotropic etching of bonded silicon-on-insulator wafers (Figure 9a). Films can then be deposited on these membranes, and if the films are under a state of sufficiently high compressive stress, they will cause the membranes to buckle. The buckling state can be characterized using a variety of tools, but optical profilometry provides a particularly straightforward technique for characterization of the buckled membrane shape, with sufficiently high vertical spatial resolution to allow determination of film stresses through comparison with models for buckling. If the compressive insulating oxide film is left as part of the membrane, membranes within a size and thickness range will be buckled in the as-fabricated state (Figure 9b). This state can be characterized before and after film deposition to measure the changes caused by the deposited film, thereby allowing characterization of the stress in the film. This technique allows determination of the stress states of both tensile and compressive films, and can also be used when films are deposited on both sides of the membranes (e.g., by chemical vapor deposition). Buckling of composite, doubly-supported beams can also be used for film stress measurements.

The second class of devices under investigation is based on micromachined cantilevers, made of single crystal silicon alone, or as part of a composite beam structure. The deflection of these cantilevers can also be characterized with very high vertical spatial resolution using an optical profilometer. We are using these simple devices for the study of thin film plasticity. Thin film plasticity is typically investigated by application of strains due to differential thermal expansion between a film and its substrate during heating and cooling. However, cantilevers can be isothermally deflected through application of a known force at their tip, causing a known strain in films deposited on the cantilevers. The stress state resulting from deformation can be characterized using optical profilometer measurements of the beam shape during and after release of the applied force. Studies of time-dependent changes in beam shapes also allow the study of time-dependent inelastic phenomena. Because micromachined cantilevers can be made very thin, Transmission Electron Microscopy (TEM) can be used to study the effects of inelastic deformation at the nanoscale. Continuous films will be studied, as will small structures (for example, submicron square dots) whose small dimensions limit dislocation formation and motion.

A third device has been developed for in-situ studies of stress evolution during film formation and during post-deposition processing. This device is made using a (110) Si wafer that is bonded to an oxidized (100) wafer and thinned to a thickness of 20µm. A cantilever beam with 4 resistors wired in a Wheatstone bridge structure is then fabricated in the (110) Si layer (Figure 10). Three resistors are oriented so as to have no piezoresistance, and one is oriented so as to have a high piezoresistance. When films are deposited on these piezocantilevers, forces exerted in the silicon cause stresses that can be characterized through measurement of the piezoresistance. In-situ stress measurements require only electrical feed-troughs in the UHV deposition system, and can be made with a sensitivity of less than 1MPa-mm, even with these relatively thick beams. These piezocantilevers can be readily heated and cooled, and can be used for measurement of stresses caused by films deposited via chemical vapor deposition (in which deposition occurs on both sides of the cantilever). Figure 11 shows stresses measured during evaporative deposition of a Cu film on a SiO_2-coated piezocantilever.

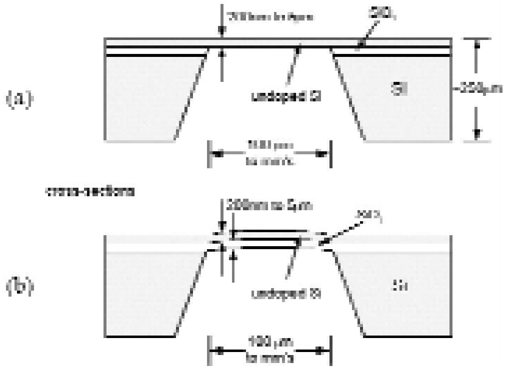

Fig. 9: (a) Micromachined single crystal Si membrane. (b) Pre-buckled composite Si-SiO$_2$ membrane

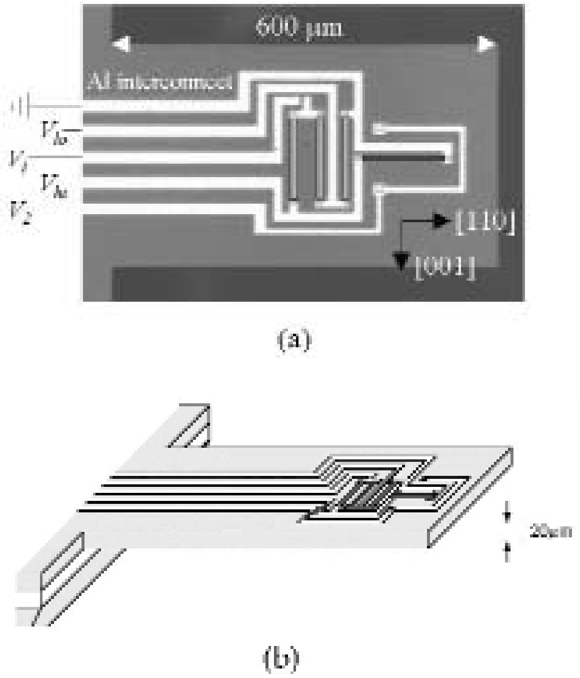

Fig. 10: (a) Top view and (b) perspective view of a micromachined piezocantilever for in-situ stress measurements during film deposition

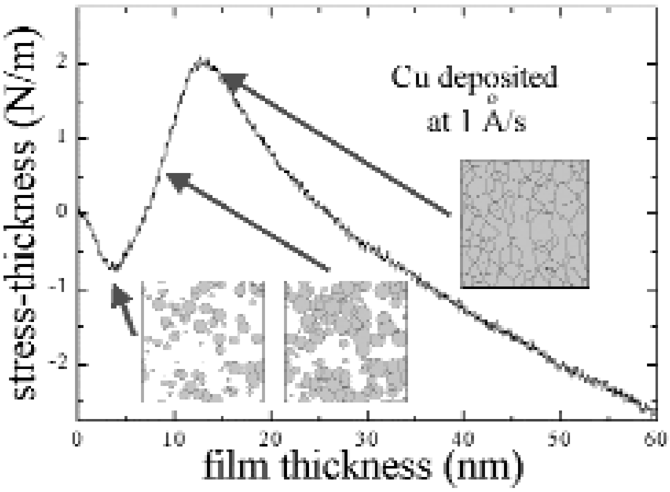

Fig. 11: The stress-thickness product as a function of film thickness, measured during evaporative deposition of a polycrystalline Cu film on a SiO$_2$-coated piezocantilever. A compressive stress develops before islands coalesce, a tensile film stress develops as islands coalesce, and a compressive stress develops during post-coalescence film thickening.