DEPOSITION TECHNIQUES AND PROPERTIES OF STRAIN
COMPENSATED LPCVD SILICON NITRIDE FILMS

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Our work on polysilicon transducers has shown that polysilicon resistors make acceptable strain sensors [1,2]. Since the devices can be deposited on a variety of substrates, transducer bodies from materials other than polysilicon become viable. Silicon nitride is particularly attractive because (1) it fits well into IC-processing, (2) is a good insulator and (3) the strain field in the material can be controlled by adjusting deposition conditions.

With a goal of developing masks for x-ray lithography, Sekimoto et al [3] describe experiments in which residual stress, optical index, optical transparency and hydrostatic strength of Low Pressure Chemical Vapor Deposited (LPCVD) silicon nitride were determined. The residual stress was determined using the bending plate method in which silicon nitride is deposited on a silicon substrate and changes in wafer deflection are measured.

Bromley et al [4] refined the measurement of intrinsic stress in LPCVD silicon nitride films using an interferometric apparatus to measure free-standing circular membrane deflection under applied pressures. A shortcoming of both these techniques is that an average or integrated strain measurement is made which provides little information about the local short order mechanical properties.

An alternate way to adjust the strain field is through ion-implantation of chemically vapor deposited silicon nitride [5]. A disadvantage of this technique is that subsequent annealing of the silicon nitride film reverses the strain compensation. The numerous reported studies involving silicon oxynitride [6] contribute little to the study of oxygen-free silicon nitride films.

Low pressure Chemical Vapor Deposited silicon nitride can be produced by reacting dichlorosilane with ammonia. Stoichiometric silicon nitride, Si_3N_4 , is produced using high ammonia/dichlorosilane volume ratios and is normally in strong tension. High dichlorosilane/ammonia gas ratios produce silicon-rich films, Si_yN_x , which exhibit compressive strain fields. The gas volume mixture can therefore be used to control the built-in strain field. In the experiment, the dichlorosilane/ammonia volume ratio was varied from 2.5 to 5.5 while maintaining a constant gas flow rate of 75.0 milliliters/minute and deposition temperature of 835°C. The tube pressure was maintained at 115 millitorr by injecting nitrogen at the pump inlet.

The fabrication of free-standing doubly supported and cantilever beams involved the low pressure chemical vapor deposition of 1.5 μm of polysilicon and .5 μm of silicon nitride over .5 μm of silicon dioxide grown on an n-type <100> silicon substrate. The silicon nitride test structures were defined using conventional photolithography and NF_3 reactive ion etching.

An aqueous KOH solution was used to remove the polysilicon under the beams thus making them free-standing. This process was used to fabricate 10 μm and 20 μm wide by .5 μm thick beams up to 320 μm long.

The fabrication of free-standing silicon nitride membranes involved depositing silicon nitride in the substrate and defining a number of windows on the back of the wafer using conventional photolithography and NF_3 reactive ion etching. An aqueous KOH solution was used to etch through the substrate leaving the nitride membranes exposed. Membranes which are 2 cm x 2 cm x .5 μm have been successfully fabricated using silicon nitride with a mild tensile built-in strain.

Optical index data was obtained using ellipsometry measurements of silicon nitride films deposited directly on silicon substrates. The index increases from 2.1 to 2.4 with increasing dichlorosilane to ammonia gas ratios of 2.5 to 5.5. The index of near-stoichiometric silicon nitride deposited at 800°C varied from 1.91 to 1.98 with dichlorosilane/ammonia ratios of .14 to .24. Optical transmission data was also obtained using the free-standing silicon nitride membranes.

Our technique of measuring compressive strain in polysilicon by beam buckling produces very good results [7]. While this technique is limited to films with compressive strain fields, a similar technique which (1) allows visual determination of the strain field and (2) gives information on local short order strain conditions is desired. Mechanical beams with built-in tensile strains will deform due to lateral buckling when subjected to a moment about the longitudinal axis. Lateral buckling causes twisting of the beam at a critical strain for a fixed geometry.

Mechanical structures which promote lateral buckling have been designed and are used to study the process-controlled strain field in silicon nitride. The figures show two views of the free-standing U-shaped beams used in our analysis. As reported, the strain field varies from highly tensile to compressive as the dichlorosilane/ammonia gas ratio increases. Processing conditions for films of a predetermined strain field and optical index have been determined.

The SEMs show two views of free-standing, U-shaped silicon nitride beams, 10 μm wide by .5 μm thick, which promote lateral buckling. Lateral buckling can be used to determine the built-in tensile strain fields in thin films.

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