Thermophysical Properties of Low-Residual Stress, 

Silicon-Rich, LPCVD Silicon Nitride Films

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As more has become known about their mechanical properties, low-residual-stress, LPCVD, silicon-nitride films [1] have seen increasing use in the fabrication of microsensor and actuator structures [2]. For the design of many sensors, it is essential to know the thermal properties of this material. Previous measurements of thermo-physical properties of silicon nitride have required samples with thicknesses in the order of millimeters [3].

In this paper, we describe measurement of the thermal conductivity, thermal diffusivity, density, and heat capacity of films with thicknesses measured in micrometers. These measurement have been carried out using two-layer composite microbridge resistors. The composite bridges consist of a bottom layer of silicon nitride and a top layer of polycrystalline silicon. Each bridge rests on two phosphosilicate-glass pedestals 3 μm thick. The low-stress nitride film was deposited in an LPCVD reactor with SiH₂Cl₂ and NH₃ flow rates of 70 and 15 sccm respectively at a pressure of 300 mT and a temperature of 835 °C. The upper polycrystalline-silicon layer is doped to form a high-resistivity region at the center of the bridge [4]. Figure 1 shows a SEM photograph of a 200 μm long and 3 μm wide composite microbridge. Figure 2 shows the two-layer structure of a composite bridge. The polycrystalline-silicon and silicon-nitride layers are 0.7 μm and 2.3 μm thick, respectively.

The thermal conductivities of both materials are obtained performing measurements of the IV characteristics [5] on an array of devices made with different thickness ratios between the silicon-nitride and polycrystalline-silicon layers. Initial experiments indicate that \( \kappa_{sn} = 0.03 \pm 0.01 \text{ W cm}^{-1} \text{ K}^{-1} \).

The density of the silicon-nitride film \( \rho_{sn} \) was determined using measurements of the weight of a wafer before and after etching a specified volume of the film. Experiments show that \( \rho = 3.0 \pm 0.1 \text{ g cm}^{-3} \).

The composite thermal diffusivity \( \alpha_c \) of the composite microbridges is extracted from the transient resistance decay of heated, heavily-doped, polycrystalline-silicon, composite-bridge resistors in a high-vacuum environment [6]. Figure 3 shows the circuit used for the measurement. A square-wave voltage of variable frequency \( V_a(t) \) is applied to the input of the circuit. In the positive cycle, both diodes are under forward bias and the full \( V_a \) is applied to heat the microbridge. In the negative cycle,
both diodes are reverse-biased, $V_b$ is applied to the bridge through a large series resistor $R_1$, and the circuit amplifies the small voltage across the microbridge. In this cycle the bridge current is small because of the large series resistance $R_1$; hence, the bridge resistor cools and its resistance decays as seen in the circuit output in Fig. 4.

It can be shown [6] that for uniformly-doped microbridges, the resistance decays exponentially with a time constant $\tau = L^2 \alpha_e \pi^2$ where $L$ is the length of the bridge resistor. From $\alpha_e$, $\kappa_e$, the material densities and their thicknesses, the heat capacities and thermal diffusivities of both materials can be found. The results of initial experiments show that $C_{nit} = 0.75 \pm 0.15 \text{ J g}^{-1} \text{ K}^{-1}$, and $\alpha_{nit} = 1.3 \times 10^{-2} \pm 6 \times 10^{-3} \text{ cm}^2 \text{ s}^{-1}$.

This paper describes the experiments and their interpretation in terms of fundamental film properties.

References


Figure 1: SEM photograph of a 200×3 μm² composite bridge

Figure 2: Two-layer structure of a composite bridge. The polycrystalline silicon and silicon nitride layers are 0.7 μm and 2.3 μm thick respectively.
$R_1 = 10\, \text{K}\Omega$

$R_2 = 1\, \text{K}\Omega$

$R_3 = 10\, \text{K}\Omega$

**Figure 3:** Circuit used for the measurement of thermal diffusivity

**Figure 4:** Typical output signal of the circuit of Figure 3