Thermal Conductivity and Interfacial Thermal Resistance: Measurements of Thermally Oxidized SiO₂ Films on a Silicon Wafer Using a Thermo-Reflectance Technique

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Abstract This article describes the development of a method to measure the normal-to-plane thermal conductivity of a very thin electrically insulating film on a substrate. In this method, a metal film, which is deposited on the thin insulating films, is Joule heated periodically, and the ac-temperature response at the center of the metal film surface is measured by a thermo-reflectance technique. The one-dimensional thermal conduction equation of the metal/film/substrate system was solved analytically, and a simple approximate equation was derived. The thermal conductivities of the thermally oxidized SiO₂ films obtained in this study agreed with those of VAMAS TWA23 within ±4%. In this study, an attempt was made to estimate the interfacial thermal resistance between the thermally oxidized SiO₂ film and the silicon wafer. The difference between the apparent thermal resistances of the thermally oxidized SiO₂ film with the gold film deposited by two different methods was examined. It was concluded that rf-sputtering produces a significant thermal resistance ((20±4.5) × 10⁻⁹ m² · K · W⁻¹) between the gold film and the thermally oxidized SiO₂ film, but evaporation provides no significant interfacial thermal resistance (less than ±4.5 × 10⁻⁹ m² · K · W⁻¹). The apparent interfacial thermal resistances between the thermally oxidized SiO₂ film and

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the silicon wafer were found to scatter significantly \((\pm 9 \times 10^{-9} \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1})\) around a very small thermal resistance (less than \(\pm 4.5 \times 10^{-9} \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}\)).

**Keywords**  Interfacial thermal resistance · Periodic method · Thermal conductivity · Thermally oxidized SiO₂ film · Thermo-reflectance

**Nomenclature**

- \(T(0)\): ac temperature of the surface of the metal film, K
- \(T_{AC}\): In-phase amplitude of the ac-temperature of the surface of the metal film, K
- \(q\): ac-power per unit volume, W \cdot m\(^{-3}\)
- \(\omega\): Angular frequency, s\(^{-1}\)
- \(k\): Wave number, m\(^{-1}\)
- \(d\): Thickness, m
- \(\lambda\): Thermal conductivity, W \cdot m\(^{-1}\) \cdot K\(^{-1}\)
- \(C\): Specific heat capacity per unit volume, J \cdot m\(^{-3}\) \cdot K\(^{-1}\)
- \(R\): Thermal resistance, m\(^2\) \cdot K \cdot W\(^{-1}\)
- Subscripts\(_0, 1, S\): Denote metal film layer, thin film layer, and substrate layer, respectively

**1 Introduction**

The microelectronics industry requires techniques for measuring the thermal conductivity of electrically insulating materials in the form of very thin films deposited on a substrate to evaluate heat dissipation across the thin films to a substrate. We have developed an advanced method to measure the normal-to-plane thermal conductivity of a very thin insulating film. In this method, a metal film deposited on the thin-film specimen is Joule heated periodically, and the ac-temperature response at the center of the metal film surface is measured by a thermo-reflectance technique. Thus, the one-dimensional model can be applied to the thermal system. The one-dimensional thermal conduction equation was solved analytically, and a simple approximate equation was derived. This method requires very simple specimen preparation in comparison with the three-omega method [1]. This method has been verified by thermal-conductivity measurements of thermally oxidized SiO₂ films on a silicon wafer [2–4]. In this article we corrected a mathematical error found in the principal equation, which has been used in our previous study. According to the corrected equation, we recalculated the thermal conductivities from the same experimental data, which have been used in our previous study [4]. As a result, these data show much improved agreement over those of VAMS TWA23 (NIST Round Robin Report) [5,6].

In this study we also tried to determine the interfacial thermal resistance between the thermally oxidized SiO₂ film and a silicon wafer separately, although by this method we can measure only the total interfacial thermal resistance, which includes the interfacial thermal resistance between the gold film and the thermally oxidized SiO₂ film, and that between the thermally oxidized SiO₂ film and the silicon wafer.