NOVEL METHOD FOR THE CHARACTERIZATION OF THIN FILMS

Introducing Frequency-Domain Thermoreflectance Measurement for the characterization of Thin Films

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THIN FILMS

Thin films thickness ranges from fractions of nanometers to few micrometers. Thin films play a major role in microelectronic and semiconductor devices. The transport of energy carriers (electrons, photons and phonons) usually gives rise to unwanted heat. So as the devices are constrained to smaller and smaller areas heat generation increases and preserving a good performance of the device becomes a challenge. Understanding the energy transfer mechanisms and thermal properties of thin films is important.

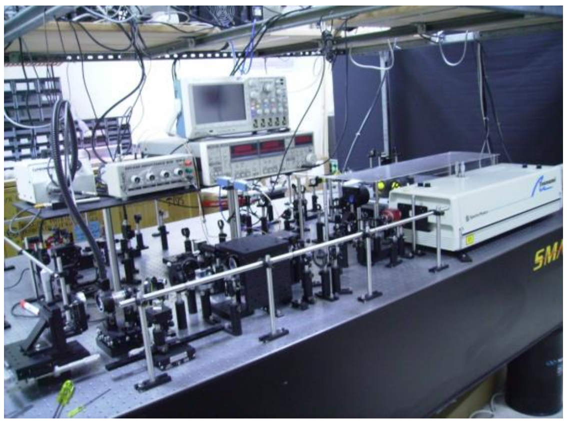

Figure 1. A photo for the Pump-Probe setup from the LENS Laboratory

PUMP-PROBE TECHNIQUE

The Pump-Probe technique is an optical technique for determining the thermal properties of thin films. The setup is illustrated in Figure 1. We use a pulsing laser that emits laser pulses of 800nm wavelength at a frequency of 80MHz. The laser beam gets split into two beams: pump and probe. The pump beam is modulated through an electro-optic modulator and then undergoes a second harmonic generation that doubles its frequency. The modulated pump beam heats the sample and gives rise to a thermal wave that propagates through the sample at a frequency identical to the pump modulation frequency. This changes the sample's optical properties.

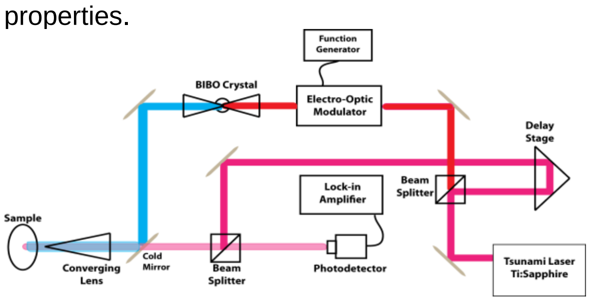

Figure 2. A scheme showing the pump probe setup.

The probe beam is delayed through a delay stage and hits the sample a bit later probing the state of the sample after the change in the optical properties occurred. The reflected probe admits a frequency component at the pump modulation frequency. This signal goes into a photo detector that converts the light signal into an electrical signal. The lock-in amplifier then detects this signal and gives back the amplitude and phase response of the probe. The lock-in amplifier data is fitted into the mathematical model describing the probe and given below:

$$Z(\omega_o) = \beta \sum_{k=-\infty}^{\infty} H(\omega_o + k\omega_s) e^{ik\omega_s \tau},$$

where τ is the delay time between pump and probe pulses, ω_s is the laser pulsing frequency, $H(\omega_o)$ is the thermal frequency response of the sample weighted by the intensity of the probe beam, and β is a factor including the thermoreflectance coefficient of the sample and the power in the pump and probe beams.

TDTR RESULTS

When the data points are taken at a specified frequency as function of time the method is called Time-domain Thermoreflectance and can extract the thermal conductivity of the sample. In figure 3 we show the best fit curve for TDTR measurement on a sample of fused silica coated with 90nm of Aluminum. The best fit value for thermal conductivity was 1.3 W/mK which is in agreement with literature values

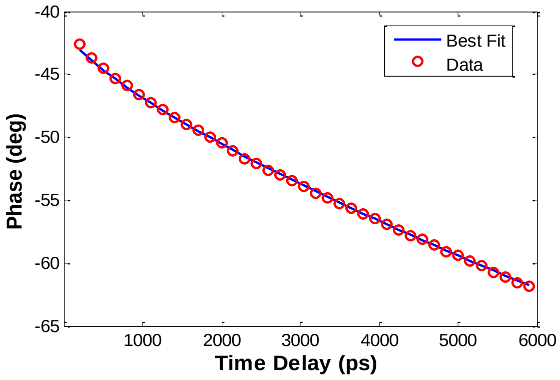

Figure 3. Sample data and best fit curve for TDTR performed on fused Silica at 5MHZ modulation frequency

FDTR: RESULTS AND APPLICATIONS

We propose a frequency domain thermo reflectance method. Instead of taking the measurement as function of the time delay between the pump and probe, we fix this parameter and vary the pump modulation frequency. This improves the sensitivity of the measurement and allows extracting the volumetric heat capacity in addition to the thermal conductivity (see 1)). Figure 4 shows the best fit curve for a thin film of silicon coated with 90nm of aluminum. The best fit value for the thermal conductivity was 144 W/mk and that for the volumetric heat capacity was 1.74 MJ/m³K and both are in agreement with literature values. One of the main application of the FDTR is the characterization of metal films (see 2)) on low thermal diffusivity substrates.

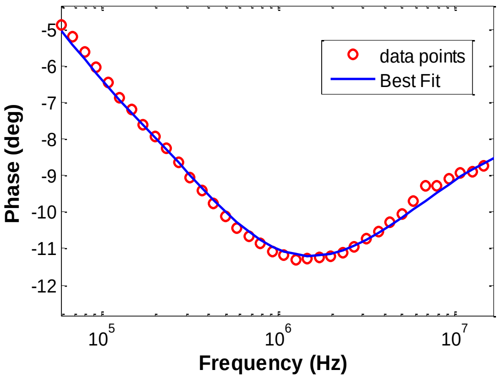

Figure 4. Sample data and best fit curve for FDTR measurement on Silicon

The method can determine the thickness and thermal conductivity of the metal film knowing the properties of the substrate. Figure 5 shows the best fit curves and best fit values for gold films of different thicknesses deposited on fused silica.

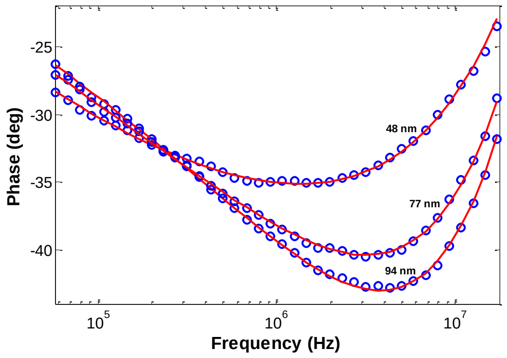

Figure 5. FDTR results for gold films of different thicknesses on fused silica substrate.

From the thermal conductivity and the Wiedemann Franz Law, the electrical conductivity of the films can be estimated in temperature and size regimes where the law

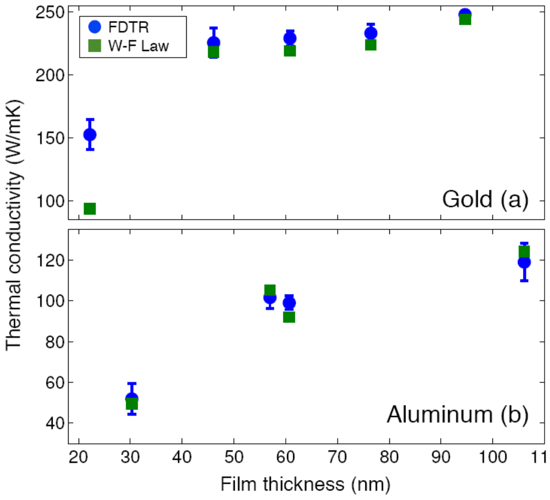

FIG. 5: Thermal conductivity data obtained for (a) Au and (b) Al films on fused silica substrates. Circles are values obtained with the FDTR method, while the squares are values computed from electrical conductivity measurements using the Wiedemann-Franz Law see (2).

REFERENCES

1) Aaron J. Schmidt, Ramez Cheaito and Matteo Chiesa "A Frequency-Domain Thermoreectance Method for the Characterization of Thermal Properties" Article in *Rev. Sci. Instrum* (2009)
2) Aaron J. Schmidt, Ramez Cheaito and Matteo Chiesa "Characterization of thin metal films via frequency-domain thermo-reflectance" Accepted for publication in *Journal of Applied Physics*