TECHNIQUE FOR MEASUREMENT OF NEAR-FIELD RADIATION HEAT TRANSFER BETWEEN PARALLEL PLANES WITH NANO-SCALE SPACING

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This paper discusses the preliminary studies for a method to measure radiative heat transfer between parallel planes with nanometric gaps. It uses a setup with two plane parallel substrates one heated, one cooled, at a fixed distance from one another. The temperature and flux measurements are carried out using external temperature probes. The heat flux is generated by an external focused light source. The stabilization is achieved by cooling using a thermoelectric device.

BACKGROUND

The radiative heat transfer between objects with nanometric gaps (roughly less than 200 nm) has been shown to be much enhanced in comparison with the heat transfer between objects in the far field (distance is much greater than wavelength).[1,2,3] A recent theoretical study by Francoeur et al.[1] has shown the spectral dependency of heat flux and resonant tunneling between two parallel thin films at sub-wavelength distances. The thin films used in the calculation were made of surface phonon-polariton (SPhP) supporting silicon carbide (SiC). The theoretical analysis describes the modes where there are SPhP coupling between the surfaces where the heat transfer is much enhanced.[1] Experimental work showing the enhancement of near field heat transfer have been performed with sphere to plane geometry[2] and using a scanning thermal microscope giving a tip to surface geometry.[3] The current work provides a method to experimentally investigate the theoretical findings by Francoeur et al. about SPhP coupling at in the sub wavelength regime and expand the scope of experimental work done by showing the near field effect of radiative heat transfer between plane parallel surfaces.

SETUP AND MEASUREMENT

This technique is developed to measure the radiative heat transfer between parallel planes with nanometer gap distances. The measurement is conducted to show the dependency of the radiative heat transfer on the temperature and the separation distance of the parallel planes. The setup consists of four parts: a heat source, heat sink, sample, measurement.

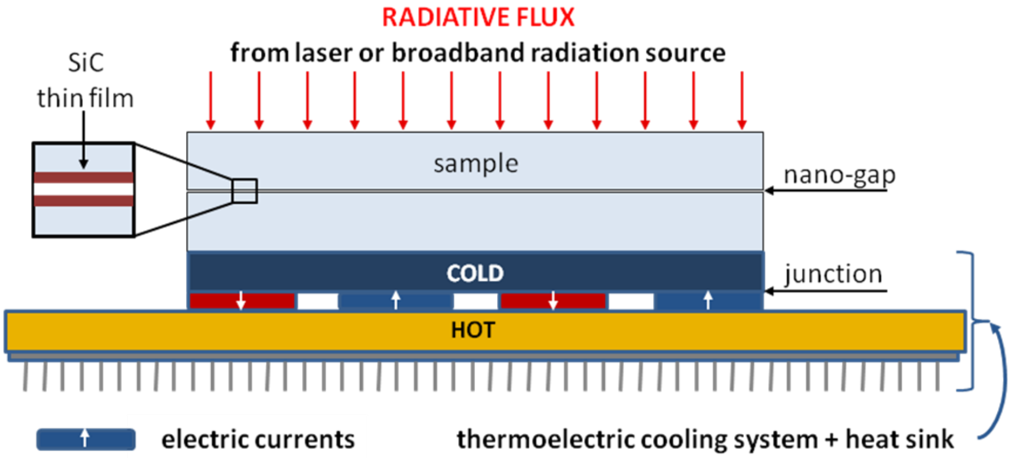

Figure 3. Test measurement setup.

The radiative flux is provided by a tungsten lamp or a laser. The goal is to have a power tunable light source that heats the surface of the sample uniformly. The filtering for optimum energy flux will be done using multiple beam splitters. The remaining light will be focused on to the sample surface. The heat sink used will be a Nextreme UP4 Optocooler™ thermoelectric cooler, (TEC) which will allow tuning of the amount the sample is cooled. The basic sample design, shown in Figure 1 consists of two substrates with SPhP supporting SiC thin film surfaces. The samples will be prepared in a near vacuum environment and the gap between substrates will be sealed to keep the near vacuum between substrates. Different samples will be fabricated according to gap length.

By tuning the intensity of light coming from the lamp or laser radiative flux source and tuning the heat flux taken out of the system by tuning the power of the thermoelectric cooler, a steady flux can be achieved. This will be monitored using external temperature probes. By setting the flux at different steady state values, the flux vs. temperature for each sample will be obtained. The temperature measurements will be made using 13μm diameter insulated temperature probes from ANBE SMT Co. These temperature probes' tips will be placed on the side of the heated sample substrate and the cooled substrate. This is how Temperatures T_1, heated surface, and T_2, cooled surface, will be obtained. The flux out of the sample will be measured using two temperature probes of the same type one at the TEC cold junction shown in Figure 1 and the other where the TEC meets the cooled substrate. The flux measured, $q_{measured}$ will be obtained by the following expression:

$$q_{measured} = \frac{(T_J - T_C)k_C}{A} \tag{1}$$

where k_C is the coefficient of heat conduction for the cold side of the TEC, T_J is the junction temperature, T_J is the temperature of the cold surface of the TEC that makes contact with the sample surface.[5]

By taking these measurements and comparing them to the theoretical transfer rate based on Plank's black body distribution, the near field enhancement of radiative heat transfer based on tunneling effects due to coulomb interaction[4] and SPhP coupling[1] for parallel planes will be shown. The radiative flux exchanged between two plane parallel surfaces with temperatures: T_1 and T_2, area: A and emissivities: ε_1 and ε_2 at far field distances is described by:

$$q_{12} = \frac{A\sigma\left(T_1^{\,4} - T_2^{\,4}\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}, \tag{2}$$

where σ is the Stefan-Boltzmann constant.[6] The near field enhancement is obtained by dividing $q_{measured}/q_{12}$. The ability of measuring the magnitude of enhancement of the near field depends on the capacity to steadily heat and cool the sample. The cooler has a lower flux capacity than the lamp or laser heat sources, so the measureable enhancement magnitude is dependent upon cooling capacity. The Nextreme UP4 Optocooler™ thermoelectric cooler has a cooling capacity at 300K of 74 (W/cm^2).[7] For surface temperatures maintained at T_1=350 and T_2=300 and spectral emissivity of SiC at temperatures between 300-350 K has been measured at around 0.25.[8] The calculated far field energy transferred from surface 1-2 per unit area using expression (2) is 5.6 (mW/cm^2). Therefore this setup will allow measurement of a near field enhancement on the order of 10^4.

SUMMARY

A system for measuring near field heat transfer between parallel planes has been proposed to both verify the theoretical findings by Francoeur et al. and to expand upon the experimental work done showing the near field enhancement of radiative heat transfer between different surface geometries to plane parallel surfaces.

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