RAD-13-P19

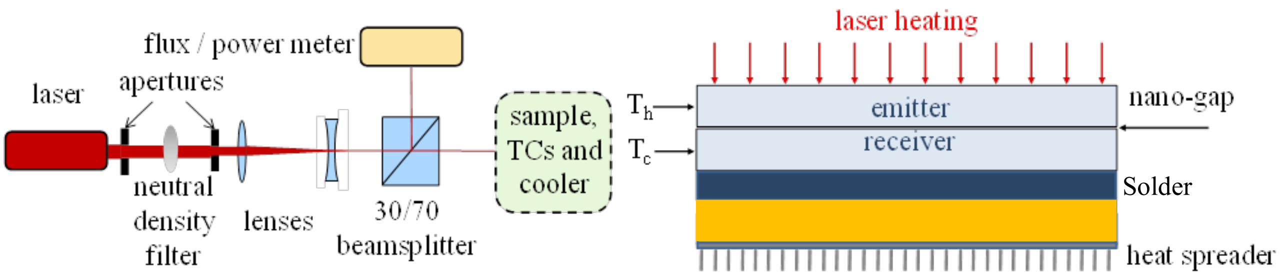
NEAR-FIELD RADIATIVE HEAT TRANSFER MEASUREMENTS BETWEEN PARALLEL PLATES

Kurt D. Webb[*,**], Zafer Artvin[***], Farhad Kazemi Khosroshahi[**],
Hakan Ertürk[**], Tuba Okutucu[***] and M. Pinar Mengüç[*]
[*]Özyeğin University, School of Engineering, Çekmeköy, Istanbul, Turkey
[**]Boğaziçi University, Dept. of Mechanical Engineering, Bebek, 34342 Istanbul,Turkey
[***]Middle East Technical University, Dept. of Mechanical Engineering, Balgat, 06530 Ankara, Turkey

ABSTRACT

The concept of near-field radiative heat transfer arises when two thermally emitting objects are brought into the sub-wavelength distance from each other. At such distance, Stefan-Boltzmann law ceases to predict the amount of radiative heat transfer between two bodies since the effects of evanescent waves come to account and increase the amount of radiative heat transfer by several orders of magnitude of the well-known black-body radiation at certain wavelengths. Evanescent waves do not propagate in the direction normal to the surface, unless a second object is brought next to the first surface by a distance that is equal to or less than the dominant wavelength. Using near-field radiative heat transfer effects in thermal systems such as thermophotovoltaic cells can increase the performance of the systems significantly. Several research groups intensively studied this phenomenon [1-10] but experimental validation of near field enhancement between parallel plates at nanoscale gaps have not been achieved so far.

This study aims at developing a novel experimental setup and a technique for measuring radiative heat transfer between two plane-parallel silicon plates apart from each other by sub-wavelength distance coated with silicon dioxide thin films (Fig. 1). The objective is to experimentally detect the near-field radiative transfer enhancement across nano-scale gaps. The plates of measured samples were bonded to silicon dioxide spacers which follow the perimeter of the sample and hold a vacuum between plates and keep the gap length between the plates constant.



(a) (b)

Figure 1. The schematic of (a) the experimental test setup and (b) the samples with parallel plates placed at nano-scale distances

Two types of samples separated by the gap distance of 100nm and 200nm were manufac ısing a novel method including nano-structuring and plasma bonding. Samples were structured to seal a vacuum between surfaces when bonded, to allow measurement in ambient conditions. The major advantage of this sample design is that the experiment can be accomplished in an atmospheric pressure room at ambient temperature, rather than in a vacuum chamber. Although the finished sample is sealed when plates are bonded together, the sample's dimensions can be determined before the bond and again after the heat transfer measurements are finished to double check parallelism. Using acoustic imaging, seals are verified by company fusion bonded the nano-structured wafers.

In order to make the experiment repeatable, micro-positioning devices are used. Heating of the plates is achieved by 200 mW red laser (670nm of wavelength) and 2W near-infrared laser (808nm of wavelength) sources and cooling of the plates is performed by a copper spreader to provide steady state heat flux through the two plates. In order to control and focus the laser beam, few optics are used (Fig. 1). The power of the laser was measured by reflecting a portion of the beam to an optical power meter. Sample is soldered on a copper heat spreader using indium-tin (InSn) solder. Total flux is measured by monitoring the heating of the laser and convective cooling of the spreader. Temperature measurements are performed using type K and T external thermocouples mounted on an x-y-z variable stage micro-positioner. Near-field radiative flux is deduced from the total flux, by accounting for the known conductive flux through spacers and loss to environment due to convection and radiation. The surface absorptivity of the samples were characterized by measuring the incident radiant energy for a pure conduction sample and comparing it with the sum of the energy transferred out of the sample by conduction, convection and radiation. Conduction out of the sample was measured by attaching the sample to a uniform 1.1 mm diameter 2 cm long protrusion from a copper heat spreader. Thermal contact resistances of the samples exist at the silica thin-film to silicon wafer interfaces and at the silica thin-film to silica thin-film interface. In order to characterize the thermal contact resistances, the same setup was used as absorptivity measurement.

The experimental results presented in Fig. 2 are compared with theoretical predictions presented in [8] and [10]. Although, it was targeted to design the samples that can hold vacuum inside the gap, however, having a vacuum between plates is an ideal case because over time, air from outside at atmospheric pressure diffuses into the gap through the sample walls introducing conduction and convection between the plates as well. In order to check the vacuum condition, a comparison is developed between measured heat transfer from hot plate to cold plate and the theoretical estimations based on difference in the measured surface temperatures.

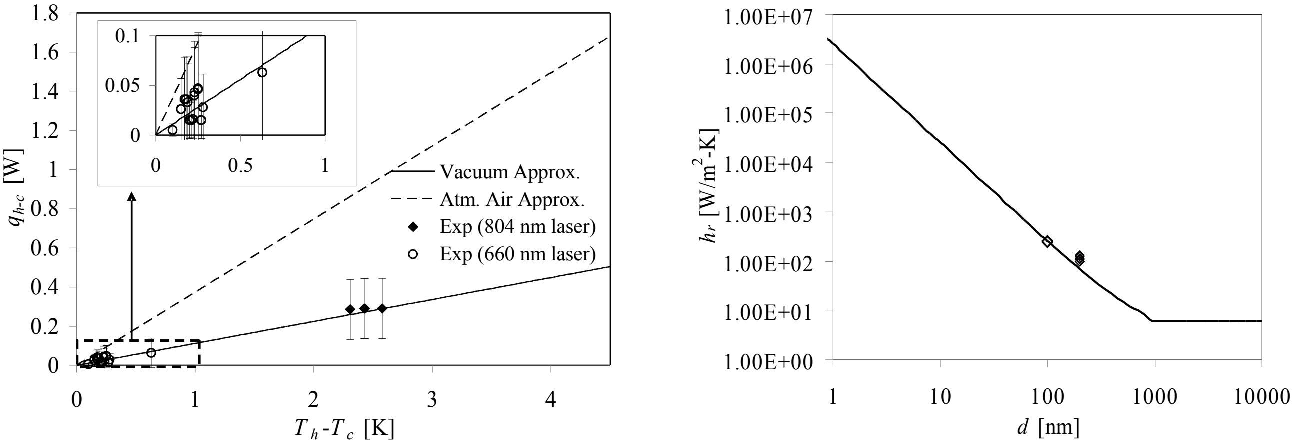


Figure 2. (a)The change of heat transfer with temperature difference for sample with 100 nm spacing. (b) Change in radiative heat transfer coefficient with sample spacing

The results presented in Fig. 2 show that the conduction heat transfer of the air inside the gap can be considered negligible and vacuum condition approximation is reasonable. However, the dominant heat transfer mode between two plates is observed to be conduction through silicon dioxide spacers. Therefore, the experimental setup must be modified to repeat the experiments where the contribution of radiation heat transfer through the gap is improved.

REFERENCES

1. Hargreaves C. M., 1969, “Anomalous Radiative Transfer between Closely-Spaced Bodies”, Physics Letters, 30A, 9, pp. 491-492.
2. Polder D., and Van M., 1971, “Theory of Radiative Heat Transfer between Closely Spaced Bodies”, Physical Review B, 4, 10, pp. 3303-3314.
3. Loomis J. J., and Maris H. J., 1994, “Theory of heat transfer by evanescent electromagnetic waves”, Physical Review B, 50, 24, pp.18517-18524.
4. Mulet J. P., Joulain K., Carminati R., and Greffet J. J., 2002, “Enhanced radiative heat transfer at nanometric distances”, Microscale Thermophysical Engineering, 6,3, pp. 209-222.
5. Fu C. J., and Zhang Z. M., 2005, “Nanoscale radiation heat transfer for silicon at different doping levels”, International Journal of Heat and Mass Transfer, 49, pp.1703–1718
6. Francoeur M., and Mengüç M. P., 2007, “Role of fluctuational electrodynamics in near-field radiative heat transfer”, Journal of Quantitative Spectroscopy & Radiative Transfer, 109, pp. 280–293.
7. Biehs S. A., Reddig D., and Holthaus M., 2007, “Thermal radiation and near-field energy density of thin metallic films”, Eur. Phys. J. B 55, 237–251.
8. Francoeur M., Mengüç M. P., and Vaillon R., 2008, “Near-field radiative heat transfer enhancement via surface phonon polaritons coupling in thin films”, APPLIED PHYSICS LETTERS, 93, 043109.
9. Joulain K., and Henkel C., 2008, “The near field correlation spectrum of a metallic film”, Appl Phys B, 93, 151–158.
10. Basu S., and Zhang M., 2009, “Maximum energy transfer in near-field thermal radiation at nanometer distances”, Journal of Applied Physics, 105, 093535.G. S. Ritchie, “Nonlinear Dynamic Characteristics of Finite Journal Bearing”, *Trans. ASME, J. Lub. Tech*., vol. 1, no. 3, pp 375-376, 1983.