Probing Near-Field Thermal Radiation between Parallel Plates using MEMS-based Platform

Mikyung Lim, Jaeman Song, Seung S Lee, and **Bong Jae Lee**

Department of Mechanical Engineering
Korea Advanced Institute of Science and Technology (KAIST)

Early Experiment on Near-Field Thermal Radiation

Cravalho, E. G., Tien, C. L. and Caren, R. P., "Effect of small spacings on radiative transfer between two dielectrics," J. Heat Transfer 89, 351-358 (1967).

MEASUREMENTS OF THERMAL RADIATION OF SOLIDS AT LIQUID-HELIUM TEMPERATURES

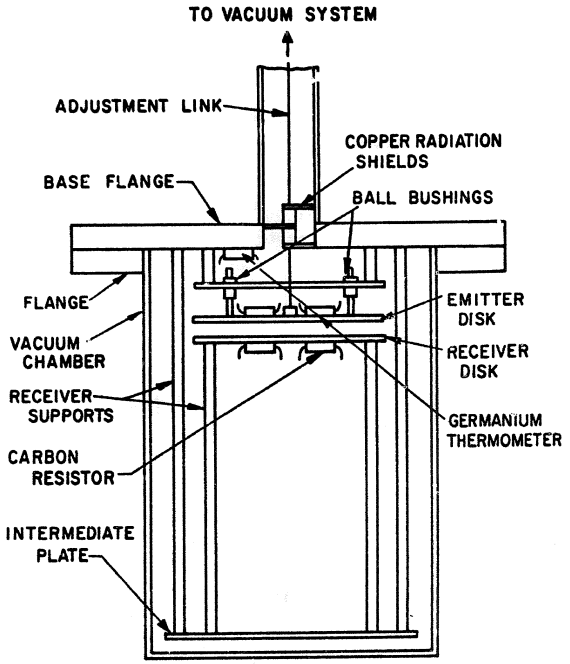
by

E. G. CRAVALHO, G. A. DOMOTO,
and
C. L. TIEN
University of California
Berkeley, California

AIAA Paper
No. 68-774

AIAA 3rd Thermophysics Conference

LOS ANGELES, CALIFORNIA/JUNE 24-26, 1968



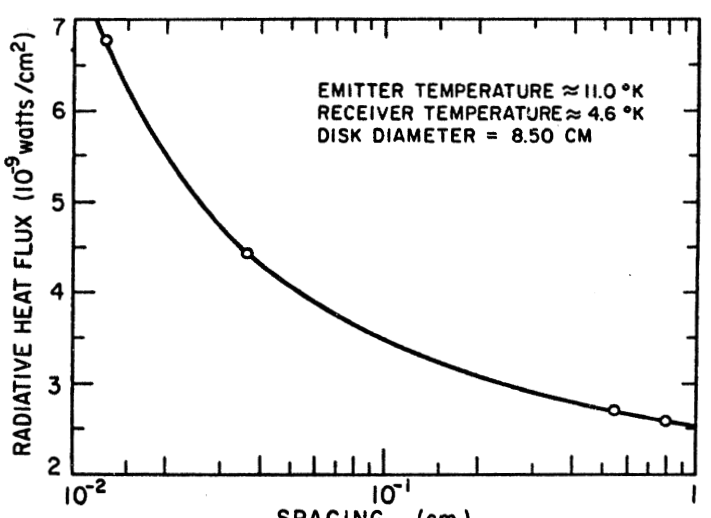
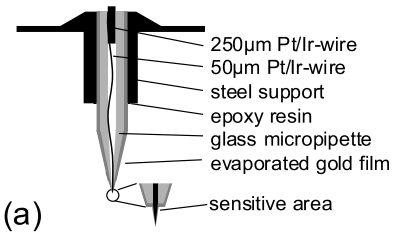
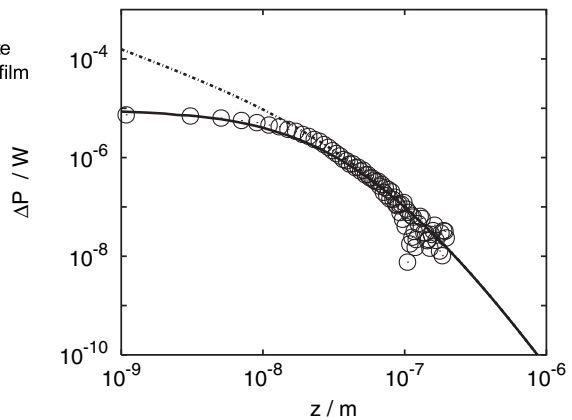


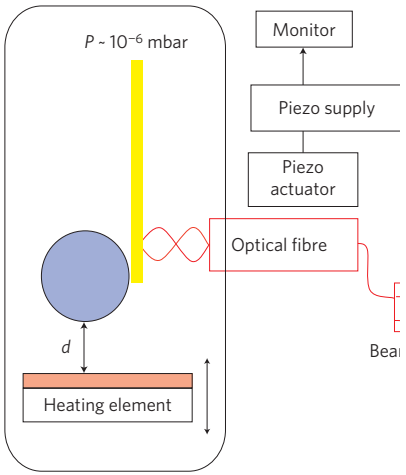
FIG. 5 RADIATIVE HEAT FLUX vs SPACING BETWEEN PARALLEL COPPER DISKS

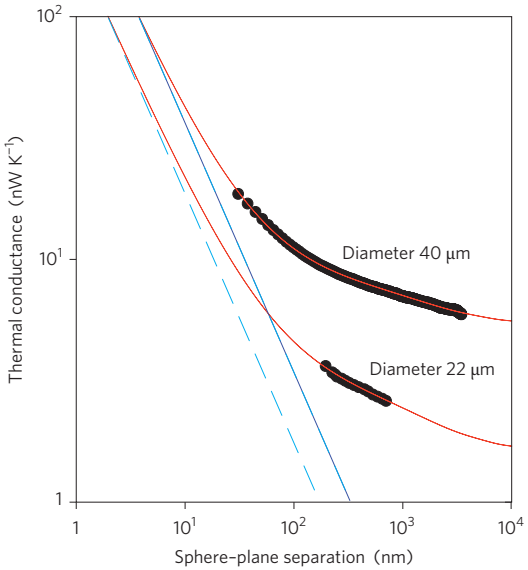
Challenges in Experimental Demonstrations (1)



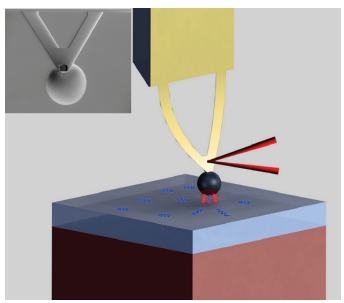


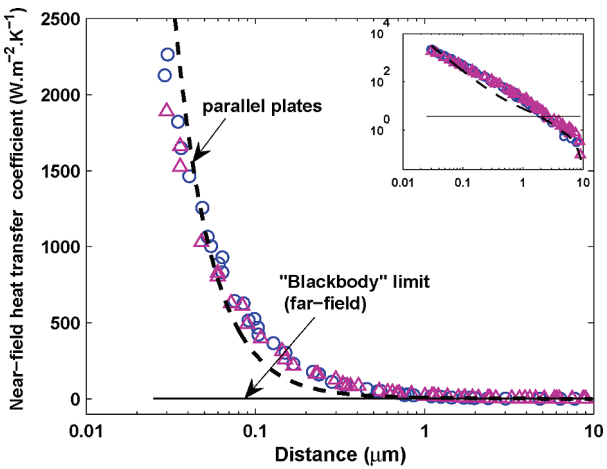
Kittel et al., *Phys. Rev. Lett.* (2005)



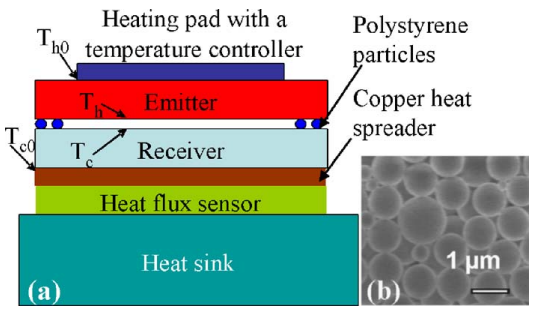


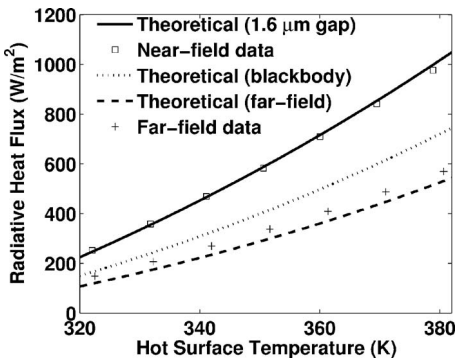
Rousseau et al., *Nature Photonics* (2009)





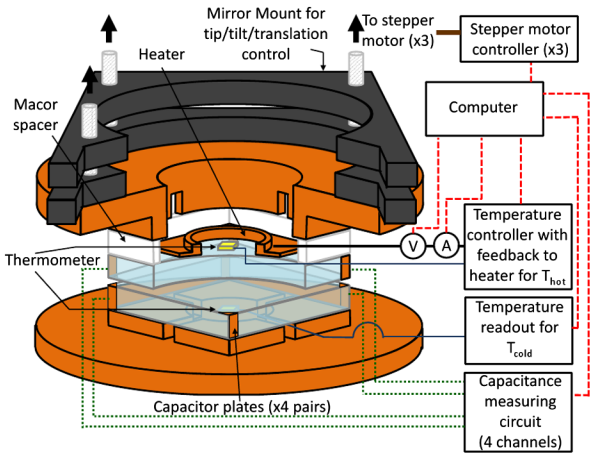
Shen et al., *Nano Lett.* (2009)



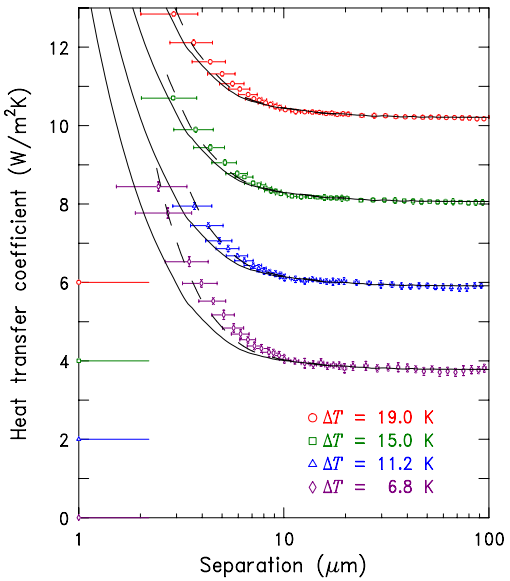


Hu et al., *Appl. Phys. Lett.* (2008)

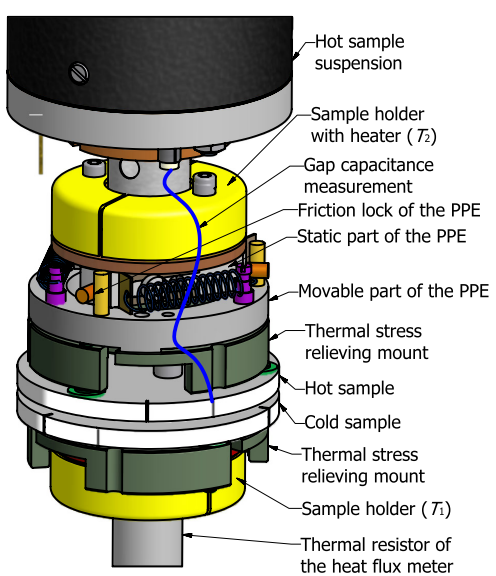
Challenges in Experimental Demonstrations (2)

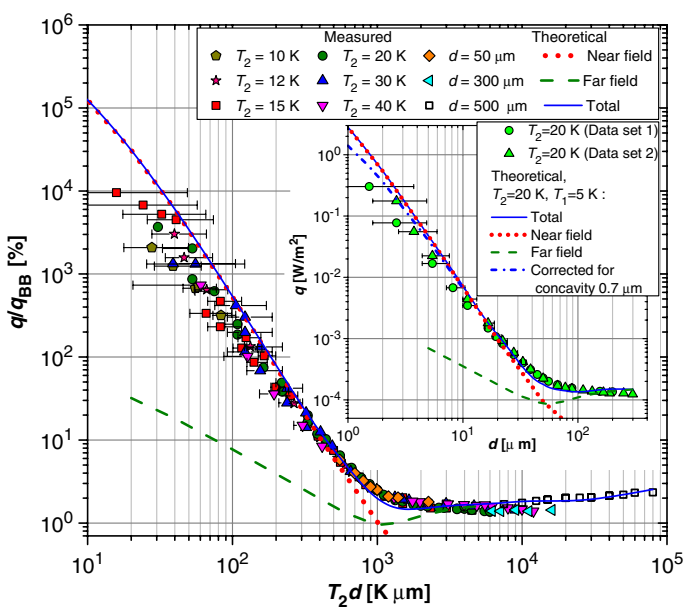


(5 mm by 5 mm) Sapphire plates



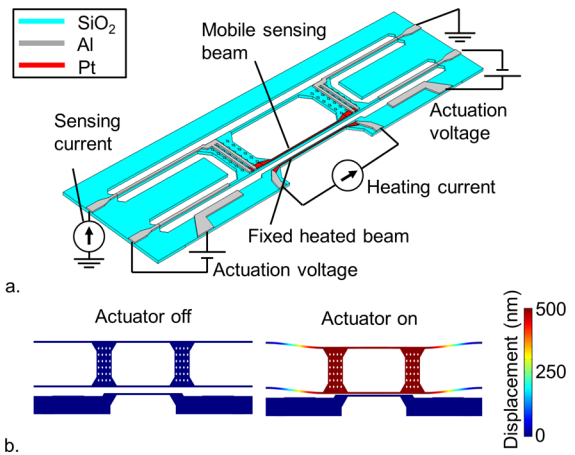
Ottens et al., *Phys. Rev. Lett.* (2011)

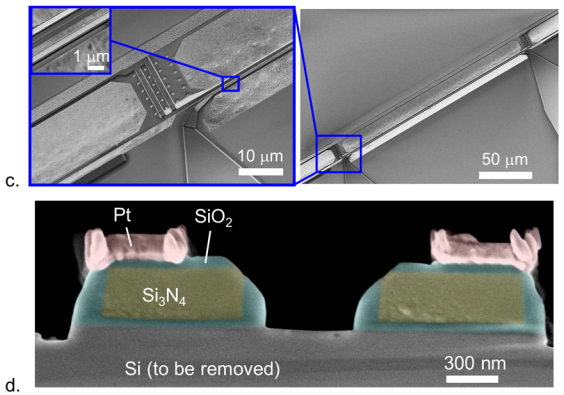


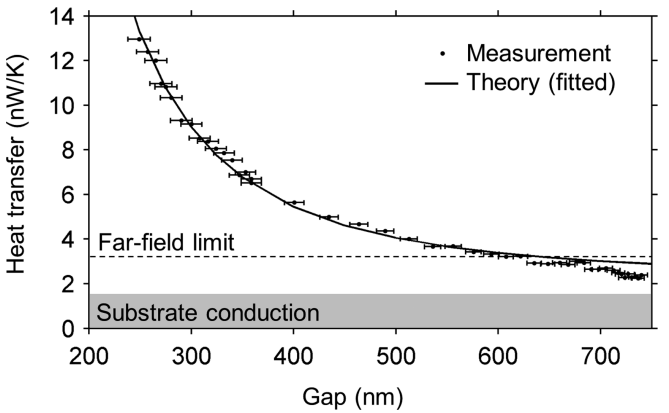


Kralik et al., *Phys. Rev. Lett.* (2012)

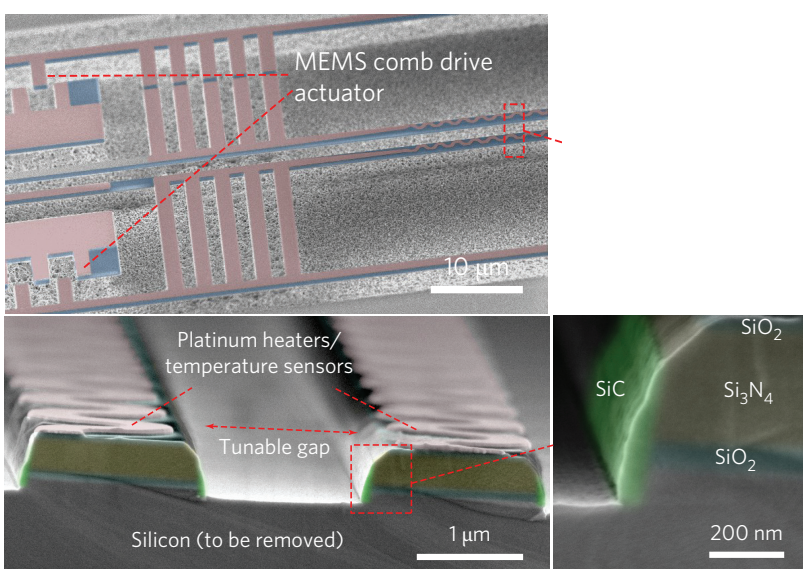
MEMS-based Measurements

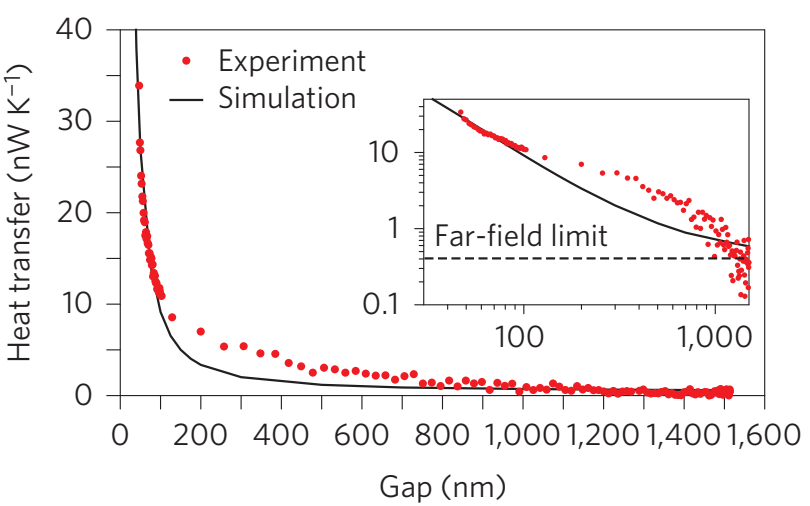






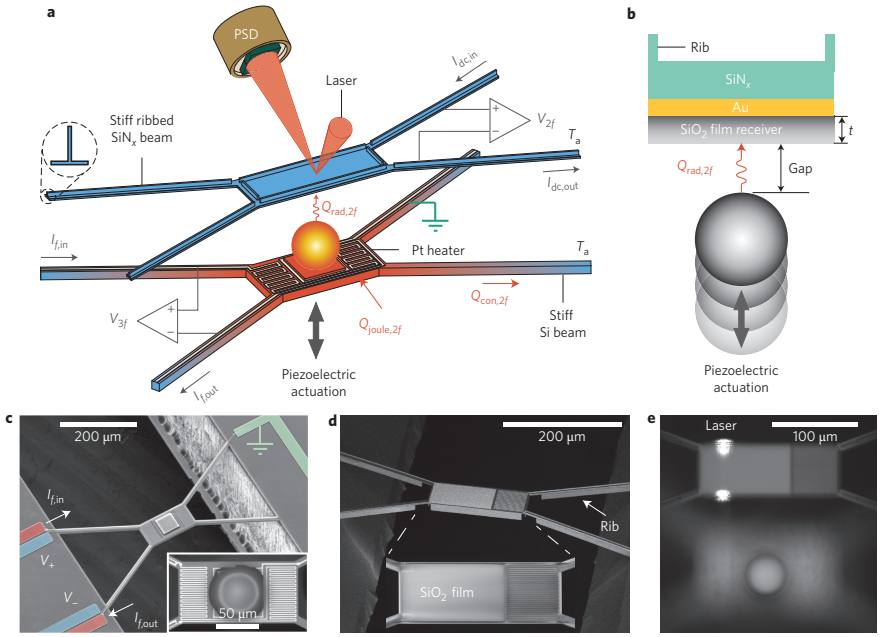
St-Gelais et al., *Nano Lett*. (2014)

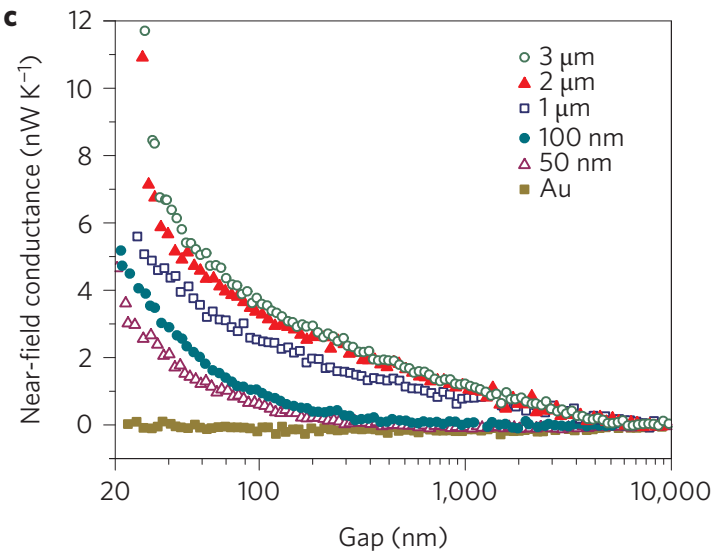




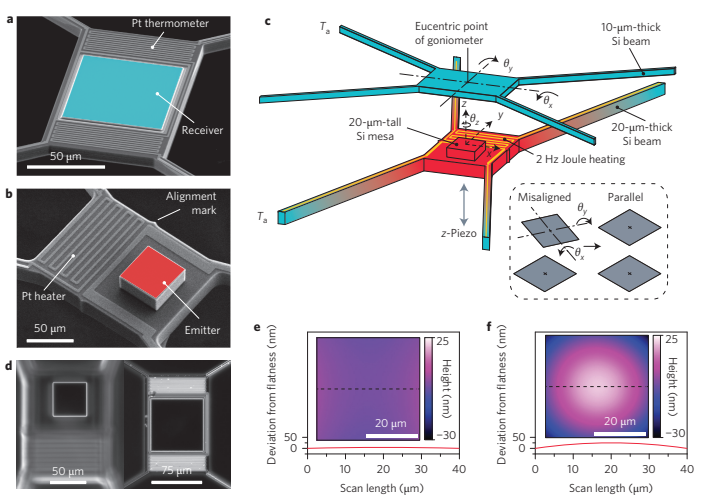
St-Gelais et al., *Nature Nanotech*. (2016)

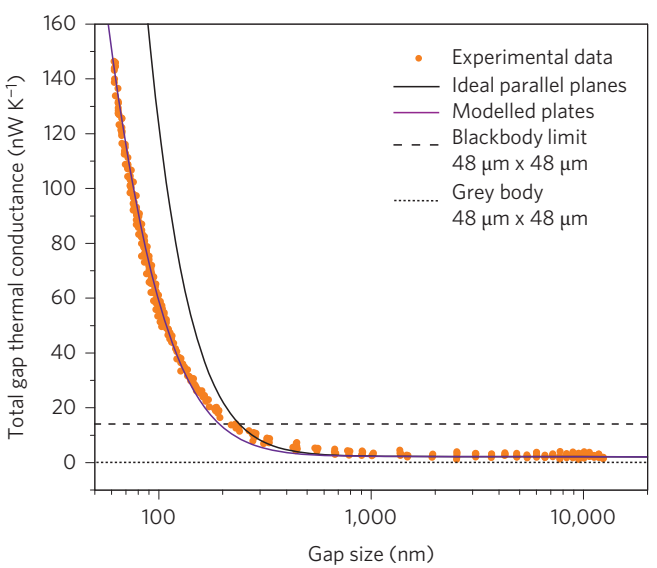
MEMS-based Measurements (2)





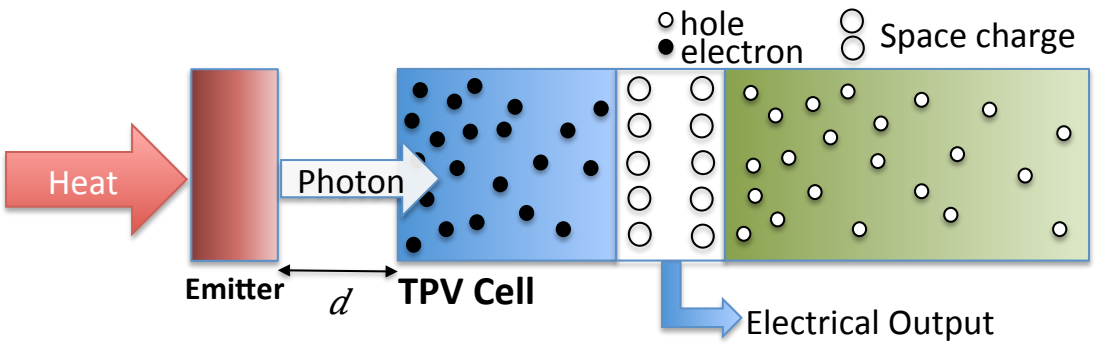
Song et al., *Nature Nanotech*. (2015)





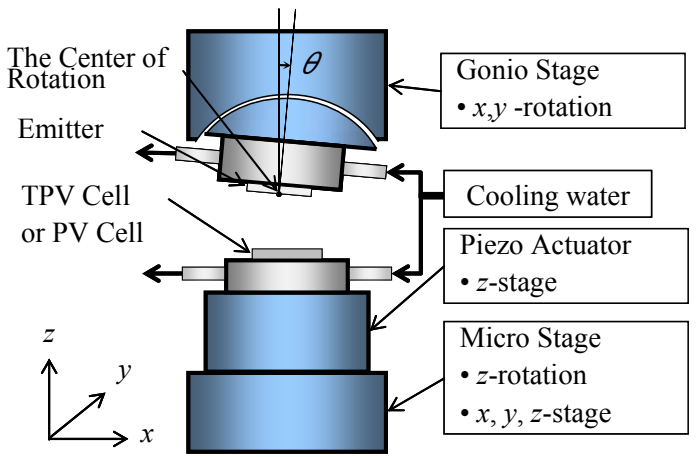
Song et al., *Nature Nanotech*. (2016)

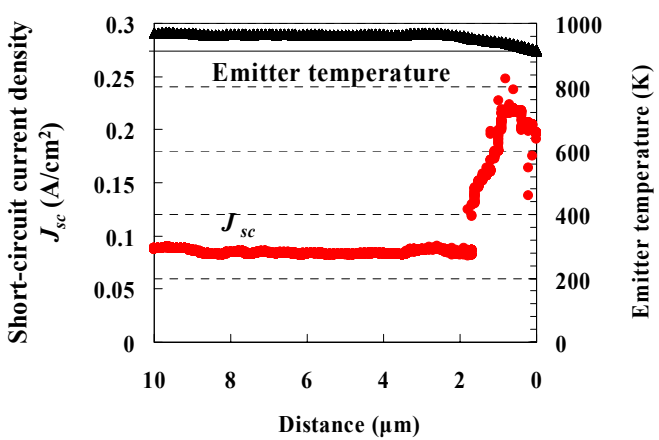
Motivation: Near-Field TPV Device



Waste Heat Energy (Infrared radiation)

Electric Power





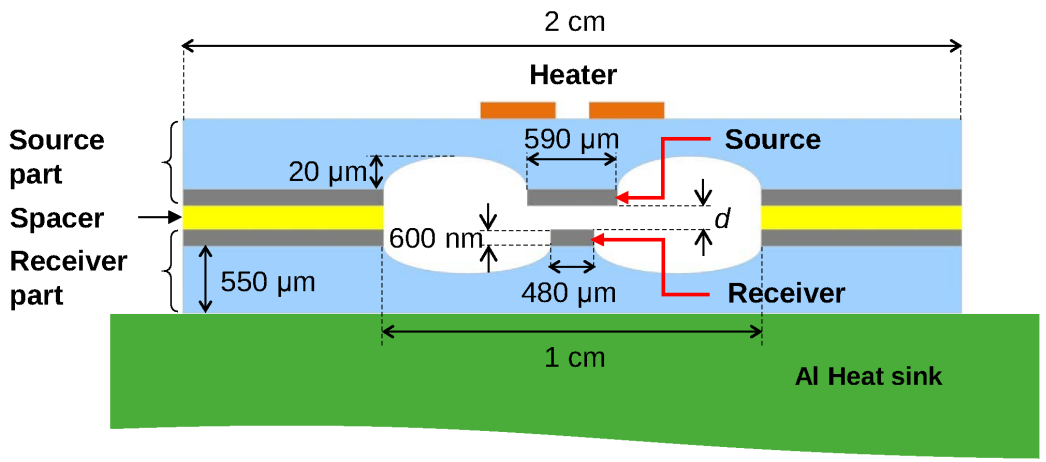
K. Hanamura's group, Tokyo Tech (AJTEC2011-44513)

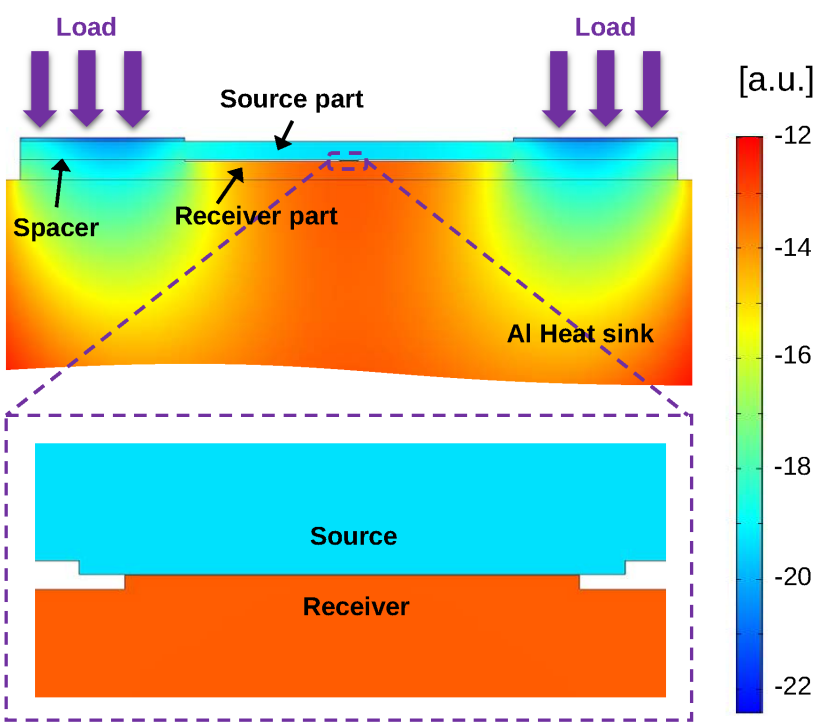
For realizing NF-TPV device, we need

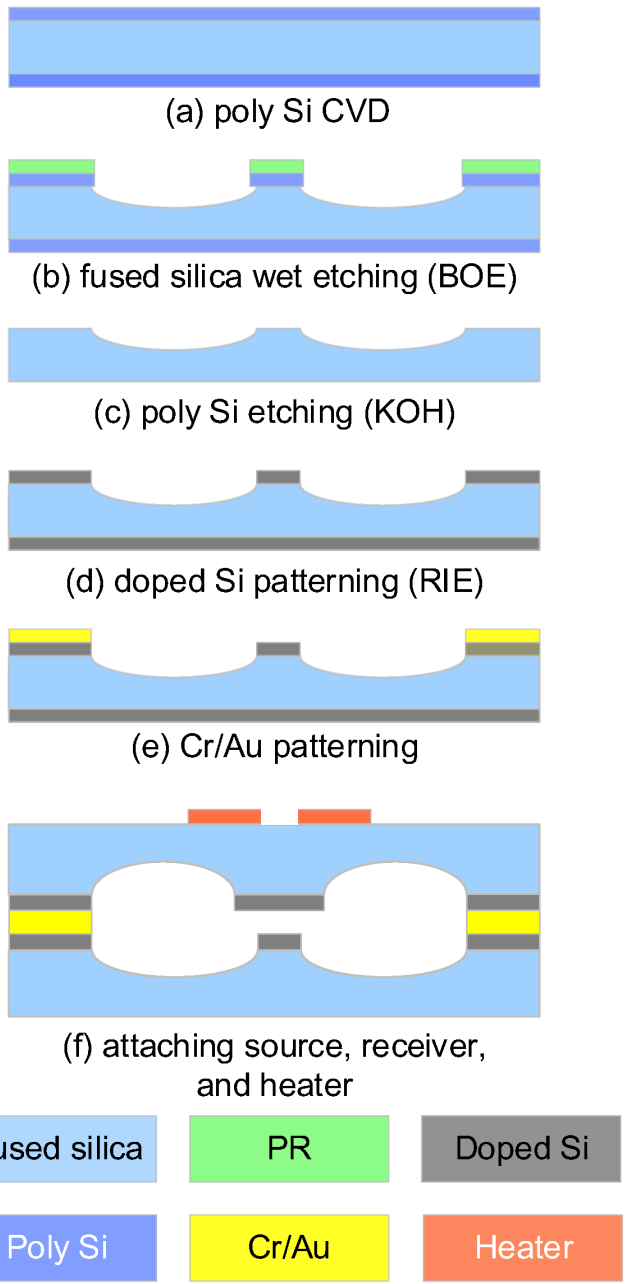
- source temperature to be as high as possible
- vacuum gap to be as small as possible
- surface area to be as wide as possible

Proposed Device

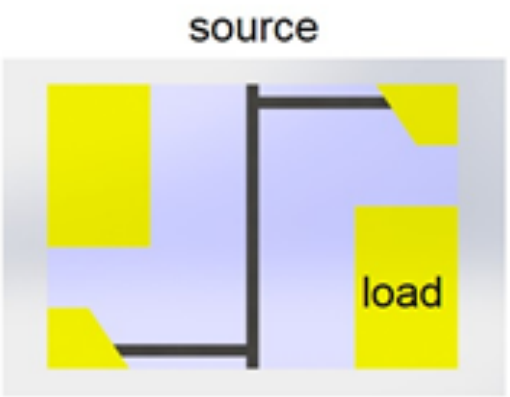
Schematics

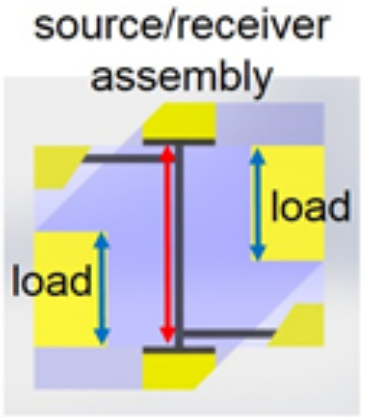


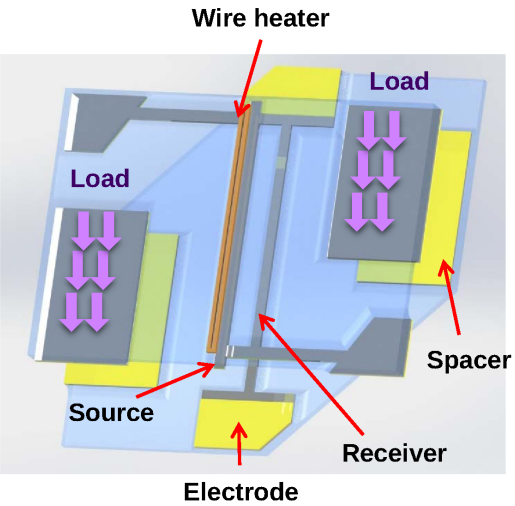


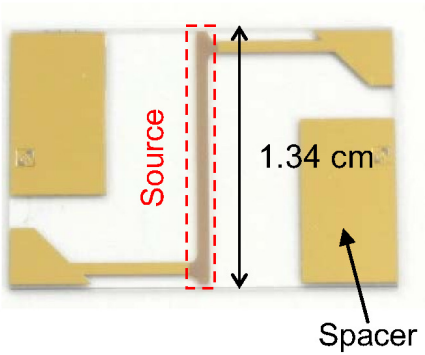


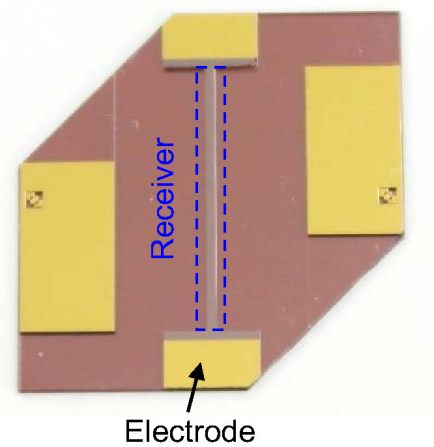
Fabricated Device

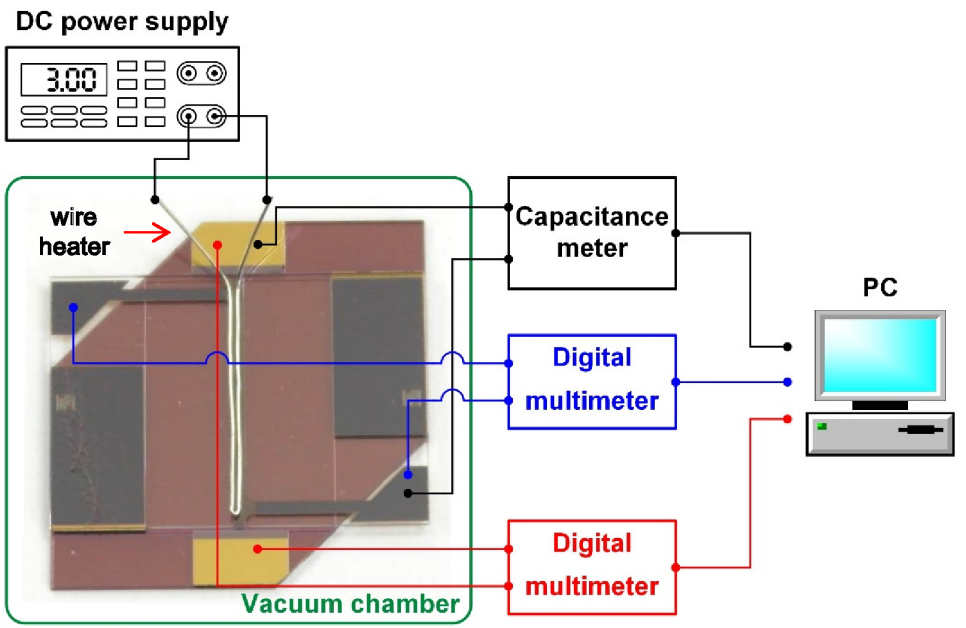




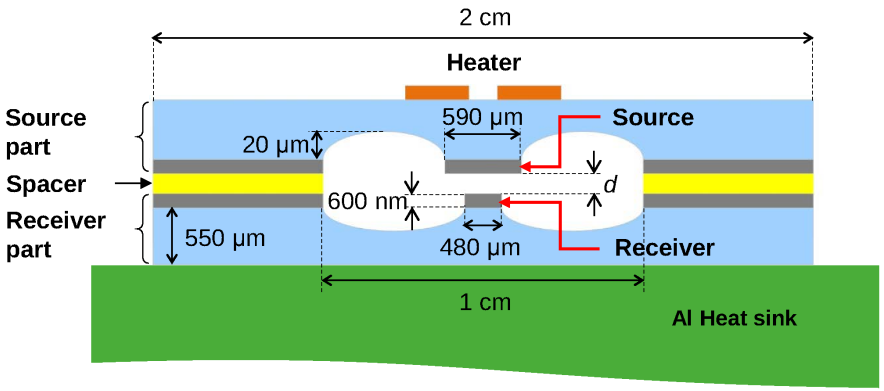


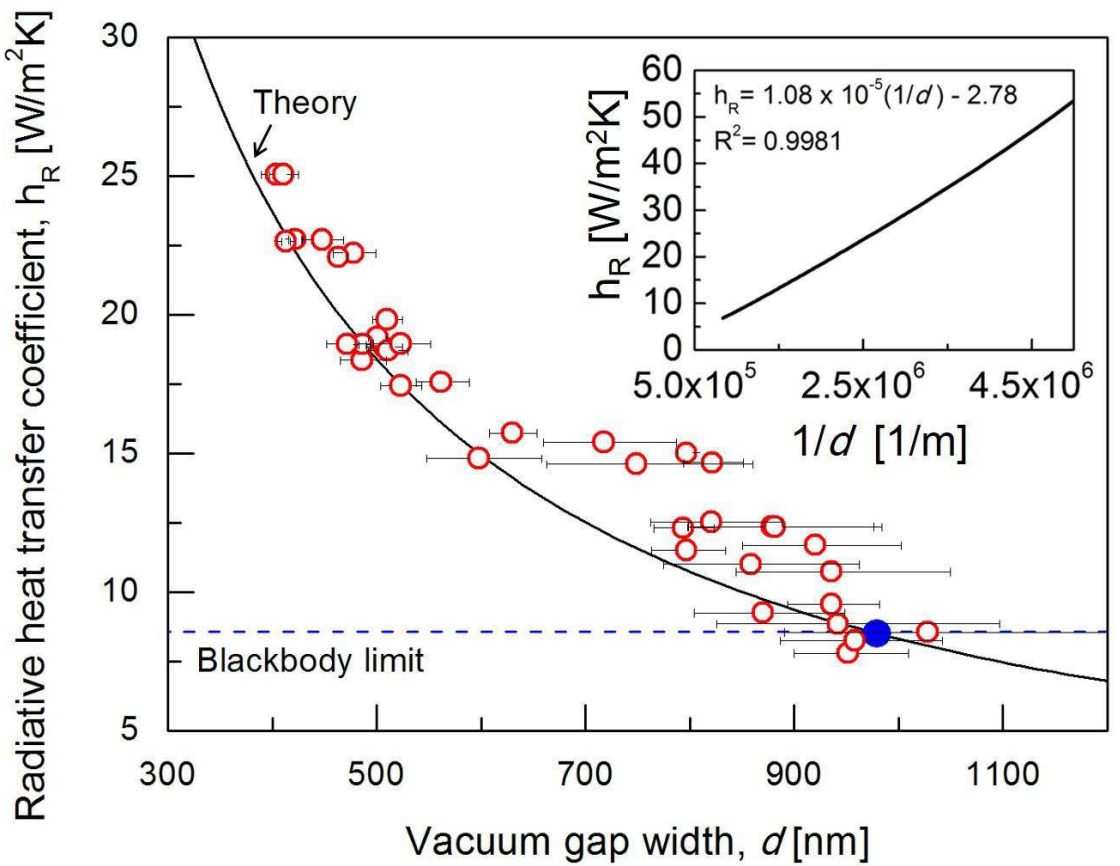






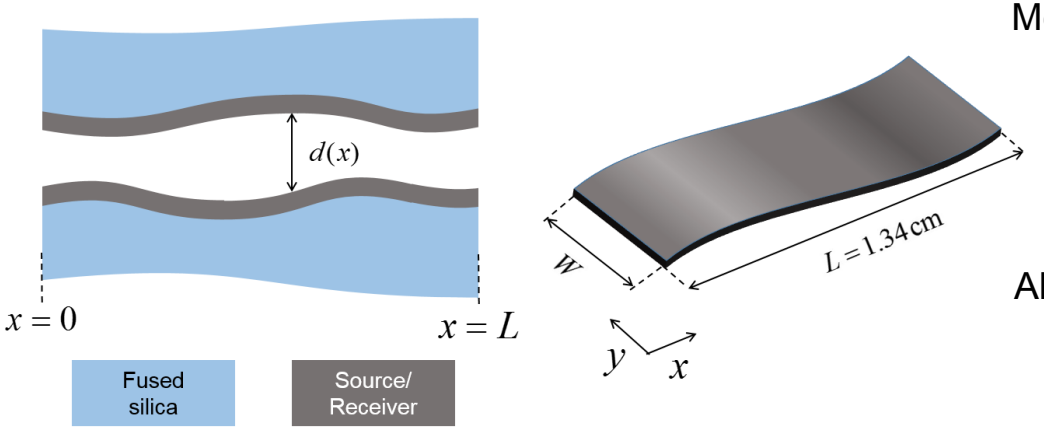
Measurement of Near-Field Thermal Radiation





M. Lim, S.S. Lee, and B.J. Lee, *Physical Review B* 91, 195136, 2015.

Advantage of the Proposed Device



Measured capacitance is related to the separation distance

$$C_m = \epsilon \frac{WL}{d_m}$$

Alternatively, $C = \int \epsilon \frac{dA}{d(x)} = \int_0^L \epsilon \frac{W dx}{d(x)} = \epsilon W \int_0^L \frac{dx}{d(x)}$

Thus, $d_m = L\left[\int_0^L \frac{dx}{d(x)}\right]^{-1} = d_{avg}$

According to Derjaguin approximation,

$$h_{R,avg} \times (WL) = \int_A h_R\{d(x)\} dA$$

Since h_R is predicted to be proportional to 1/d when the vacuum gap width varies from 200 nm to 1200 nm,

$$h_{R,avg} = \frac{a}{L}\int_0^L \frac{dx}{d(x)} + b = \frac{a}{d_{avg}} + b$$

The average radiative heat transfer coefficient is nothing but the radiative heat transfer coefficient at the average gap distance.

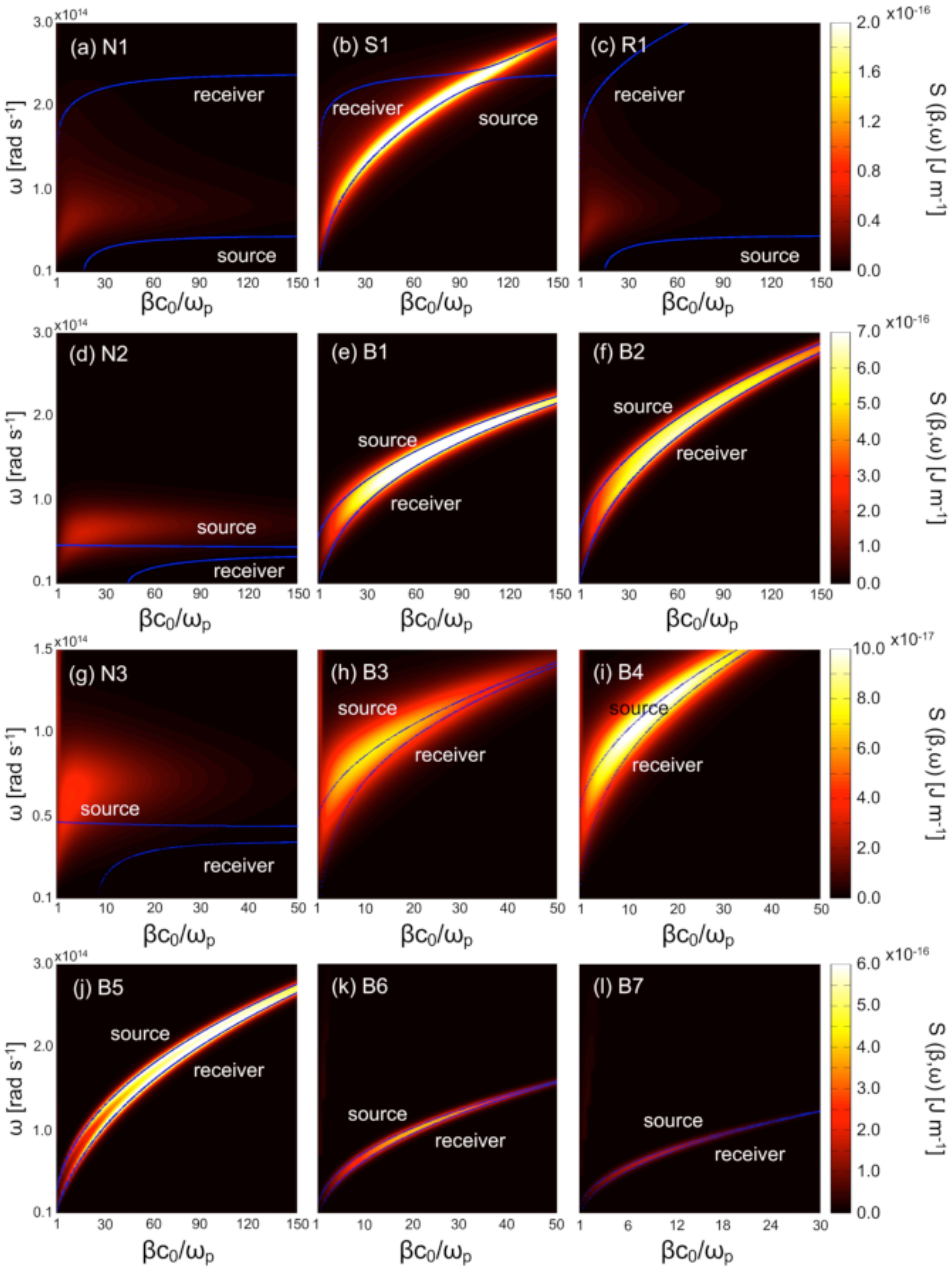
Remaining Challenges

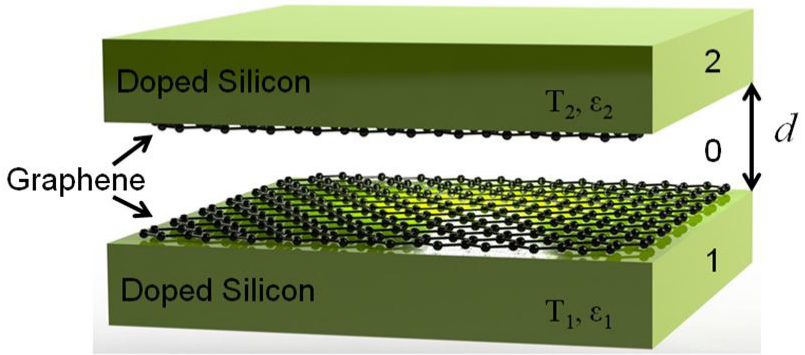
- Near-field enhancement of radiative heat transfer becomes significant when the vacuum gap distance between parallel plates is less than 200 nm. But maintaining such a small gap distance between parallel plates (with wide surface area) is extremely challenging.

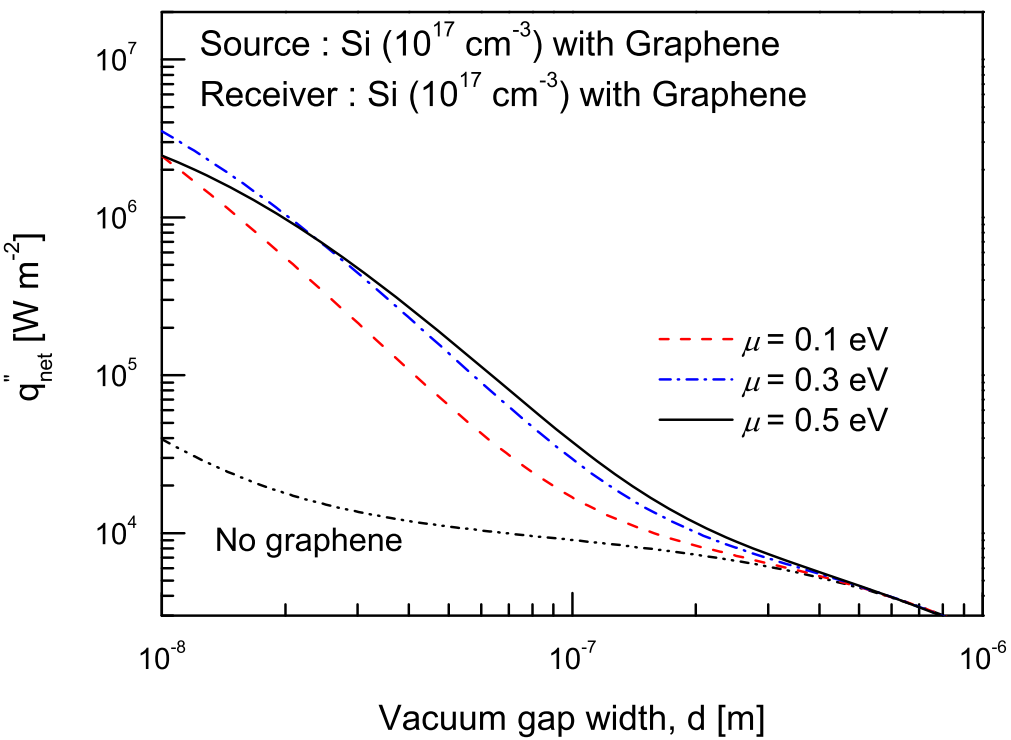
- One of the most prominent applications of near-field radiation is a thermophotovoltaic (TPV) energy conversion, which requires planar geometry with wide surface area.

- We may also need to seek alternatives. For instance, we can modify surface conditions using optical metamaterials including graphene in order to further enhance the near-field thermal radiation at achievable vacuum gap distance.

Spectral Control of Near-Field Radiation

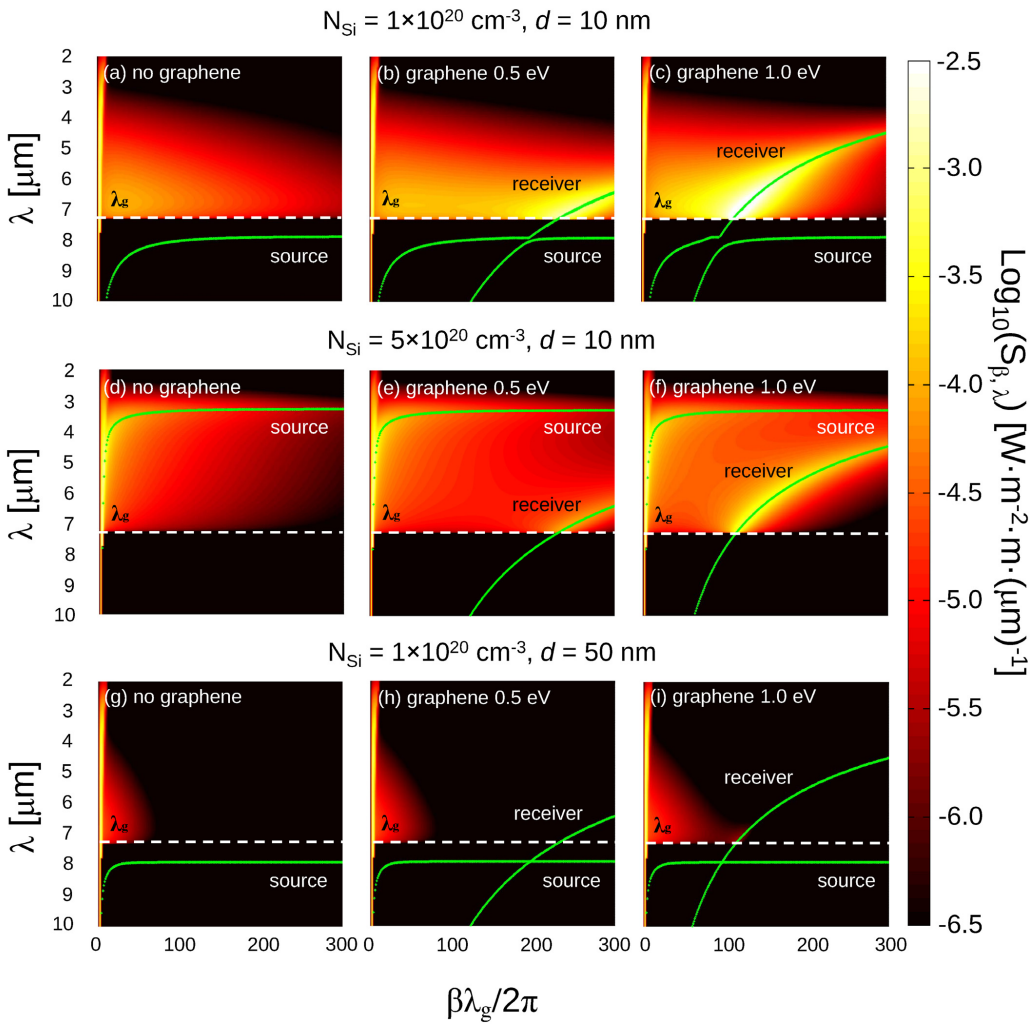


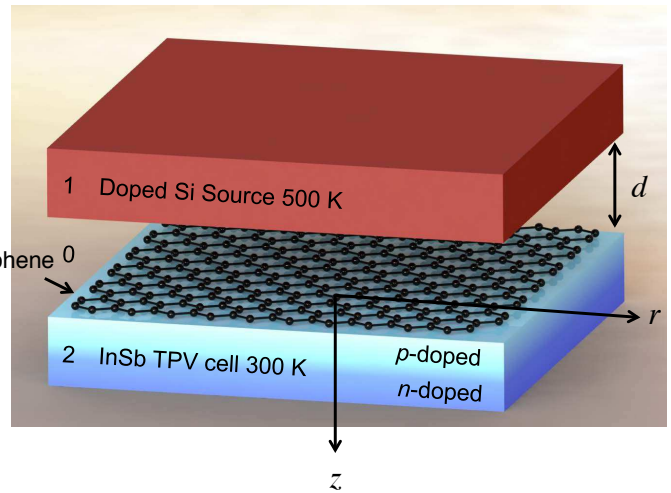


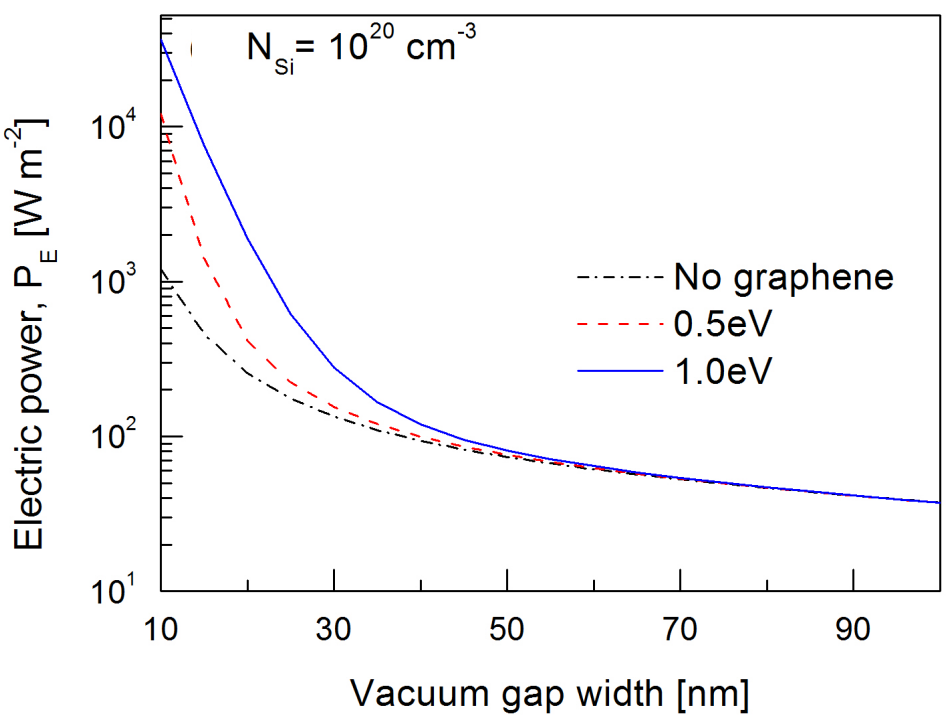


M. Lim, S.S. Lee, and B.J. Lee, *Optics Express* 21, 22173–22185, 2013.

Graphene-Assisted NF-TPV System

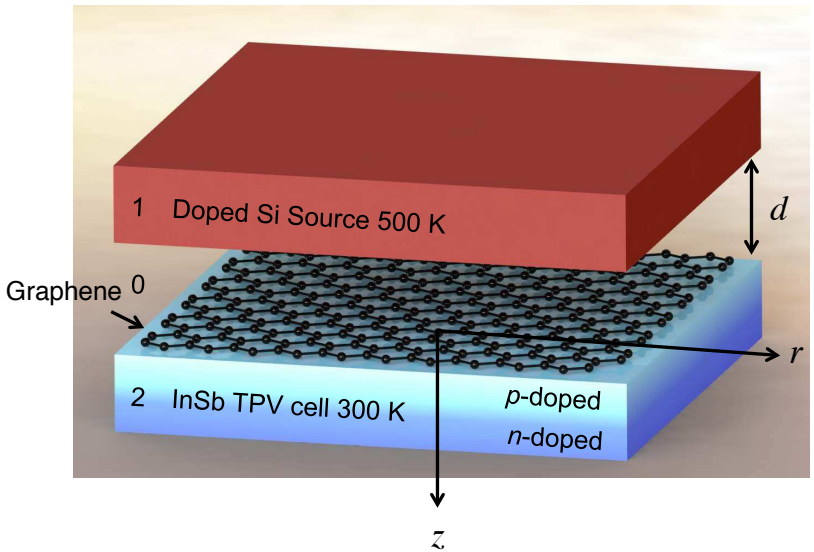


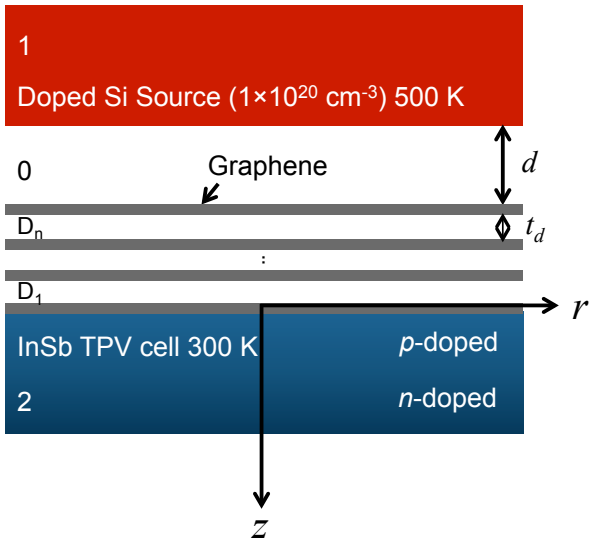


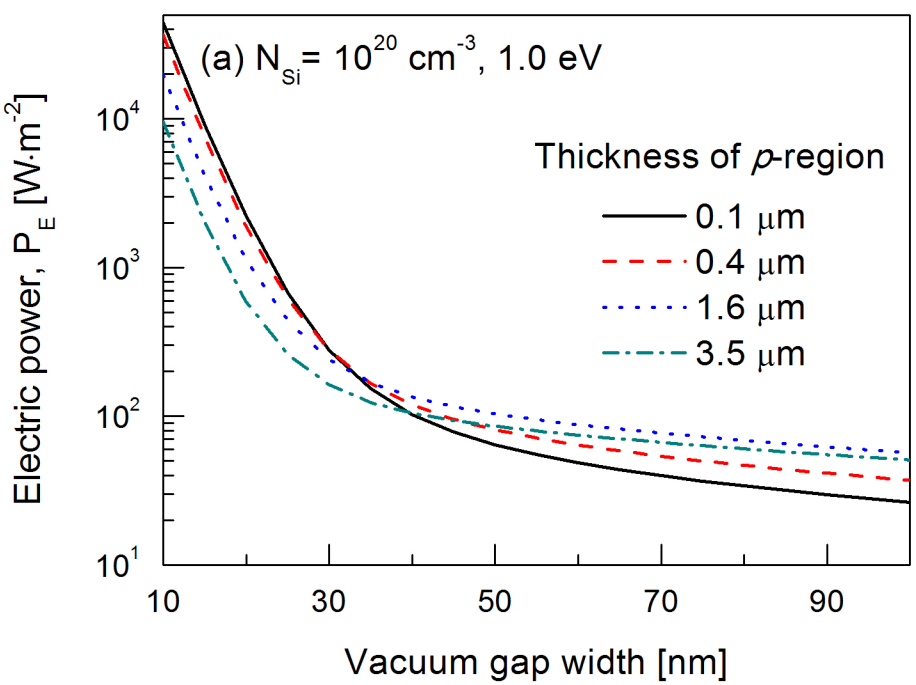


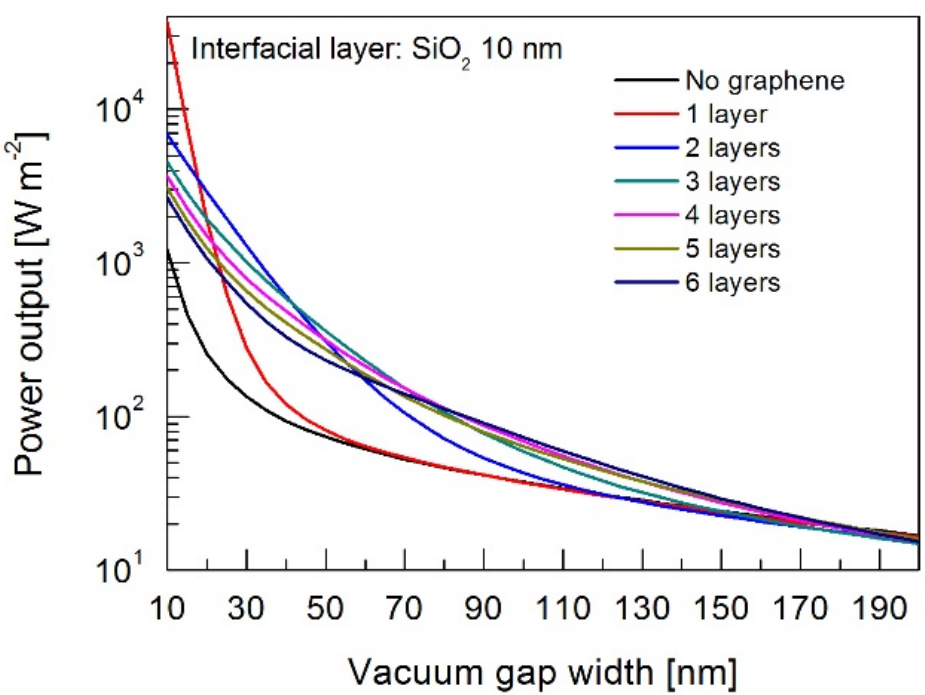
M. Lim, S.M. Jin, S.S. Lee, and B.J. Lee, *Optics Express* 23, A240-A253, 2015.

Extending Graphene's Effects to Longer Distances



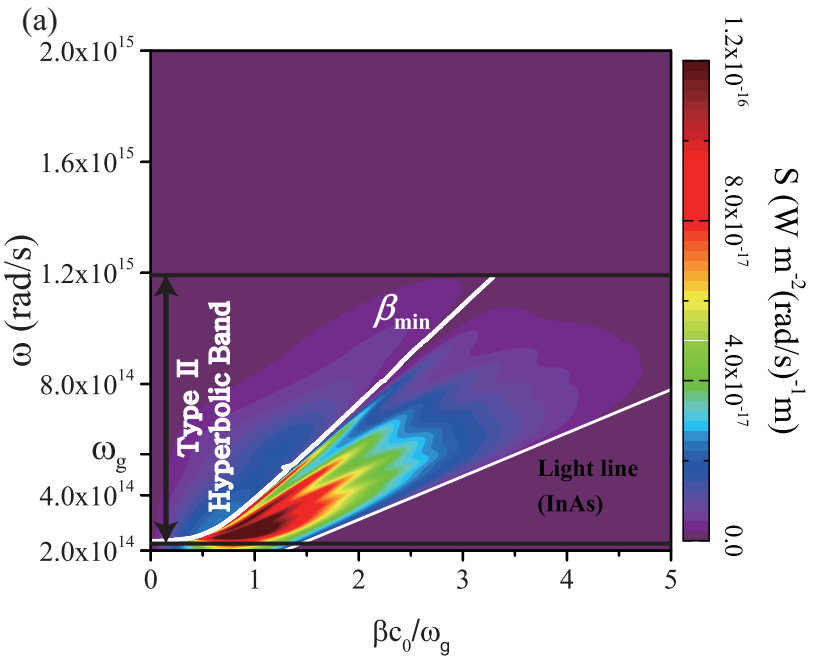


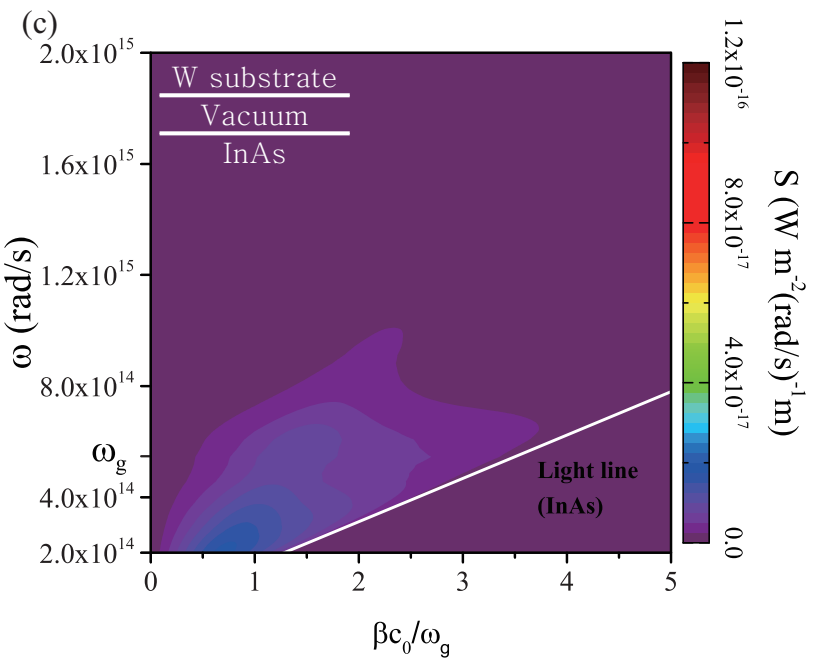


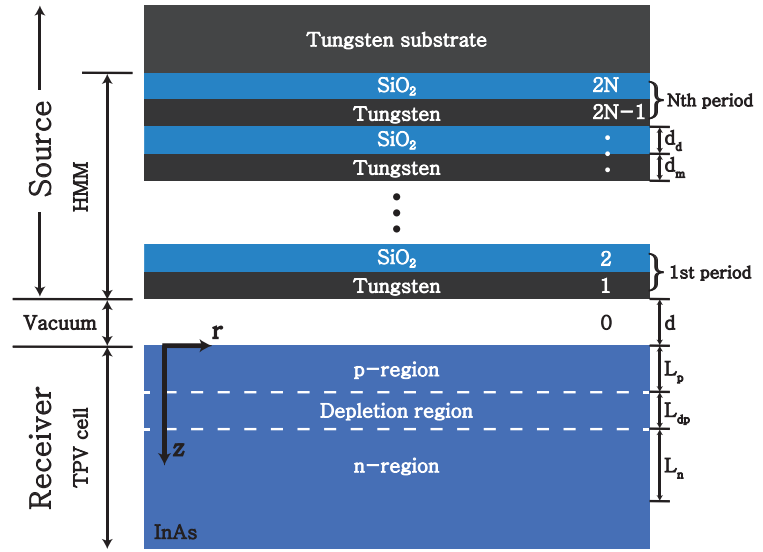


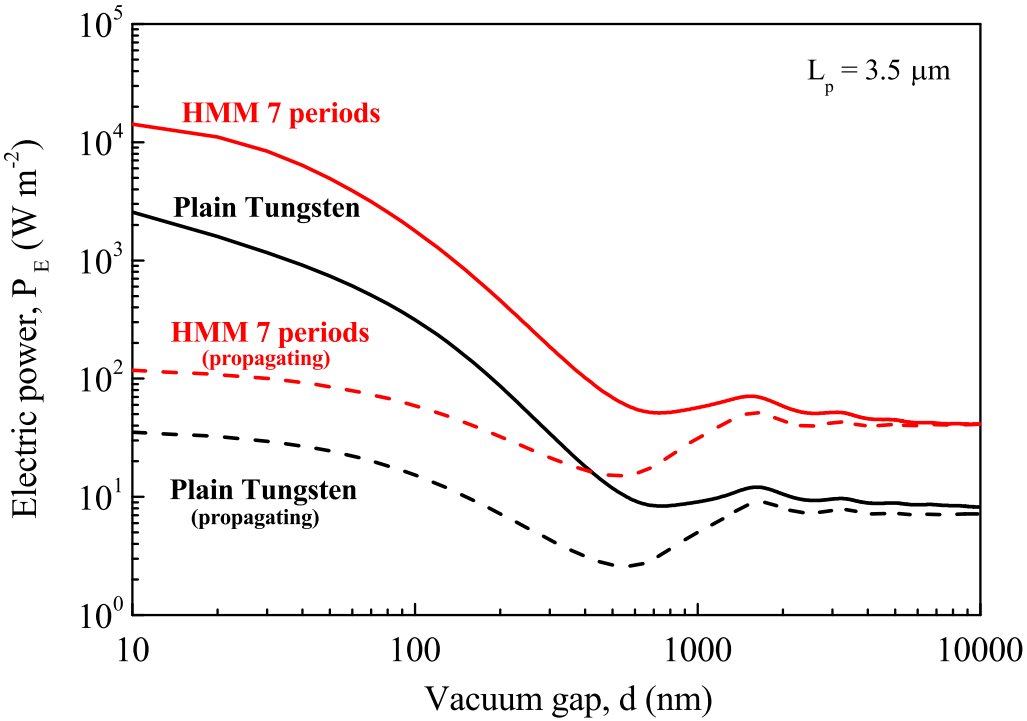
M. Lim, S.S. Lee, and B.J. Lee, *8th International Symposium on Radiative Transfer, RAD-16, June 6-10, 2016* .

HMM-Assisted NF-TPV System









S.M. Jin, M. Lim, S.S. Lee, and B.J. Lee, *Optics Express* 24, A635-A649, 2016.

3rd International Workshop on Nano-Micro Thermal Radiation (NanoRad)

(June 26-28 2017 at KAIST, South Korea)

Co-Chairs:

Bong Jae Lee, KAIST, South Korea

Mathieu Francoeur, University of Utah, USA

Long Shuai, Harbin Institute of Technology, China