PERFORMANCE ANALYSIS OF NEAR-FIELD THERMOPHOTOVOLTAIC DEVICES CONSIDERING ABSORPTION DISTRIBUTION

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ABSTRACT. This paper elucidates the energy transfer and conversion processes in near-field thermophotovoltaic (TPV) systems, considering local radiation absorption and photocurrent generation in the TPV cell. Radiation heat transfer in a multilayered structure is modeled using the fluctuation-dissipation theorem, and the electric current generation is evaluated based on the photogeneration and recombination of electron-hole pairs in different regions of the TPV cell. The effects of near-field radiation on the photon penetration depth, photocurrent generation, and quantum efficiency are examined in the spectral region of interest. The detailed analysis performed in the present work demonstrates that, while the near-field operation can enhance the power throughput, the conversion efficiency is not much improved and may even be reduced. Subsequently, a modified design of near-field TPV systems is proposed to improve the efficiency.

NOMENCLATURE

D	diffusion coefficient (m^2/s)
d	width of the vacuum gap (m)
$\mathbf{E}$	electric field vector (V/m)
E_g	energy bandgap (J)
$\overline{\overline{\mathbf{G}}}$	dyadic Green's function (m^{-1})
g	photogeneration rate of electron-hole pairs (m^{-3})
$\mathbf{H}$	magnetic field vector (A/m)
J	photocurrent density (A/m^2)
$\mathbf{j}$	fluctuating current density (A/m^2)
$\mathbf{k}$	wavevector (cm^{-1})
N	carrier concentration (m^{-3})
n^0	intrinsic carrier concentration (m^{-3})
P_R	radiative heat flux (W/m^2)
P_E	electric power density (W/m^2)
$\mathbf{S}_\omega$ or $\mathbf{S}_\lambda$	time-averaged Poynting vector [W/(m^2 rad/s) or W/(m^2 μm)]
$s_{z,\lambda}$	wavevector-based Poynting vector in the z-direction [W/(m^2 μm cm^{-1})]
u	surface recombination velocity (m/s)
V_{oc}	open-circuit voltage (V)

Greek

β	parallel component of $\mathbf{k}$ (cm^{-1})
γ	perpendicular component of $\mathbf{k}$ (cm^{-1})
δ	penetration depth (m)
ε	relative electric permittivity
ε_0	vacuum permittivity, 8.854×10^{-12} (F/m)
η	conversion efficiency
η_q	quantum efficiency
μ_0	vacuum permeability, $4\pi\times10^{-7}$ (H/m)
τ	relaxation time (s)

Subscripts

A	acceptor
D	donor
dp	depletion region
e	electron
g	bandgap
h	hole
l	l^{th} layer
n	n-region
p	p-region
s	source layer

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