Photon Effect Observed in Nano-Rectenna for Optical Frequencies

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Introduction

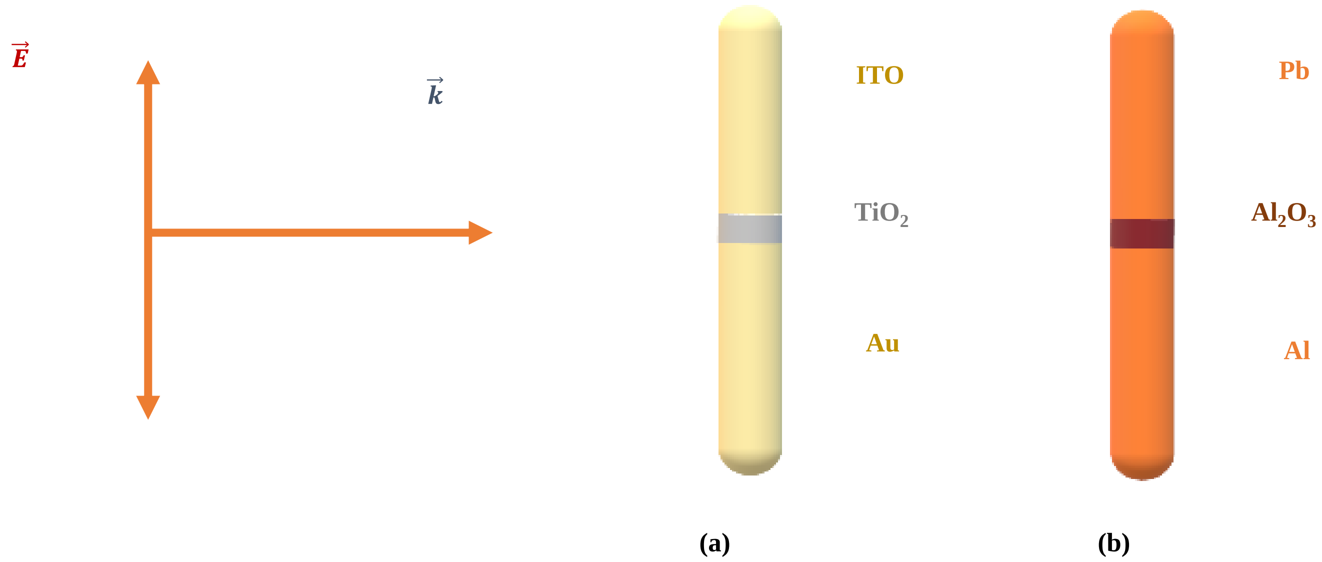


Figure 1: The illustration of MIM nanorod rectennas (rectifying nano-antennas) structure with the insulator about 2 nm thickness: (a) MIM Au-TiO_2-ITO nanorod. Indium tin oxide (ITO) is a type of transparent material that could be used as metal-like mirror for MIM device. (b) MIM Al-Al_2O_3-Pb nanorod. The photons or TM polarization wave would incident from the side of the diode [1].

Energy Band Profile

Metal	W(eV)	Insulator	ϕ(eV)
Ag	4.26	Ta_2O_5	3.83
Al	4.28	Al_2O_3	1.78
Au	5.1	Cr_2O_3	3.76
Cu	4.4	TiO_2	3.9
Ti	4.33	Nb_2O_5	4.23
W	4.55	$SrTiO_3$	3.9
Nb	3.99	$PbTiO_3$	3.1
Pb	4.25	$BaZrO_3$	2.5
Pt	5.65	$PbZrO_3$	3.2
Sn	4.38	ZrO_2	2.5
Ta	4.25	Si_3N_4	2.1
Cr	4.5	SiO_2	0.9
ITO	4.45	Vacuum	0

Schematic of the equilibrium circuit of the device with illumination

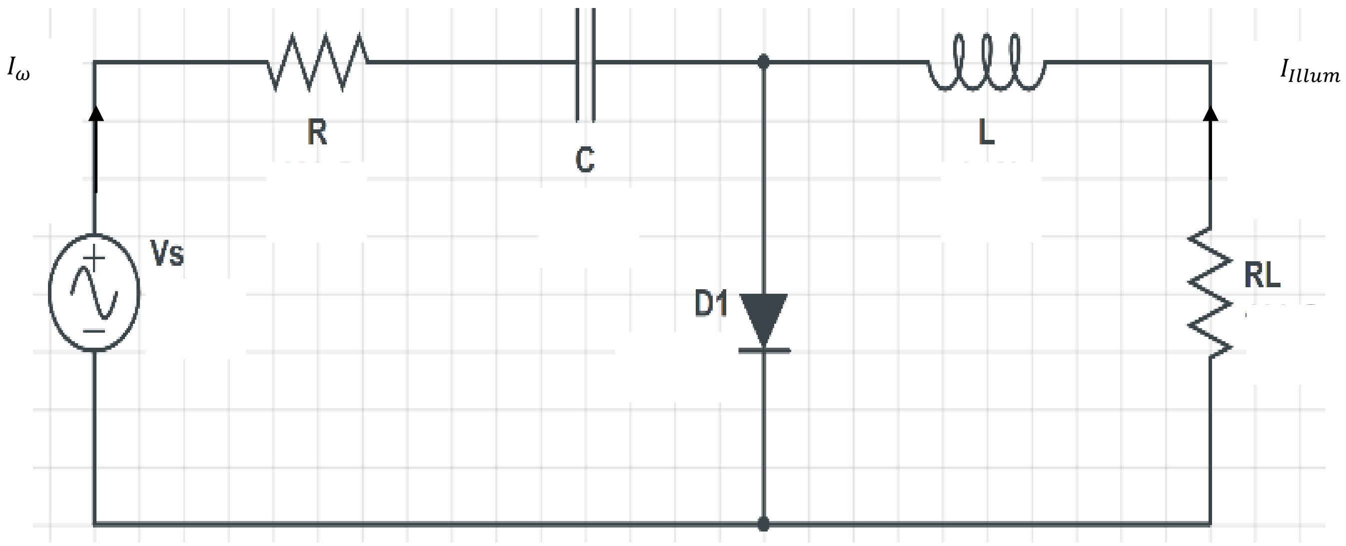


Figure 2: Schematic of the equilibrium circuit of the device with illumination.

Photon Effect: Where Einstein meets Maxwell

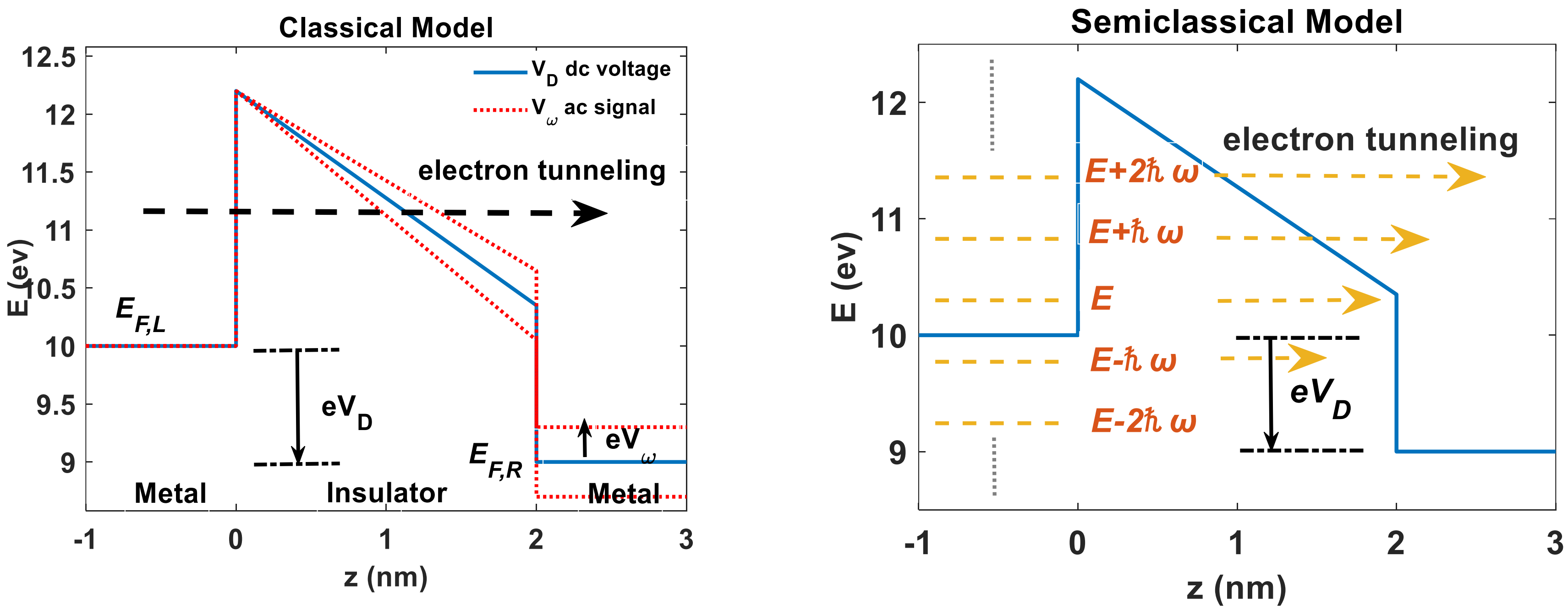
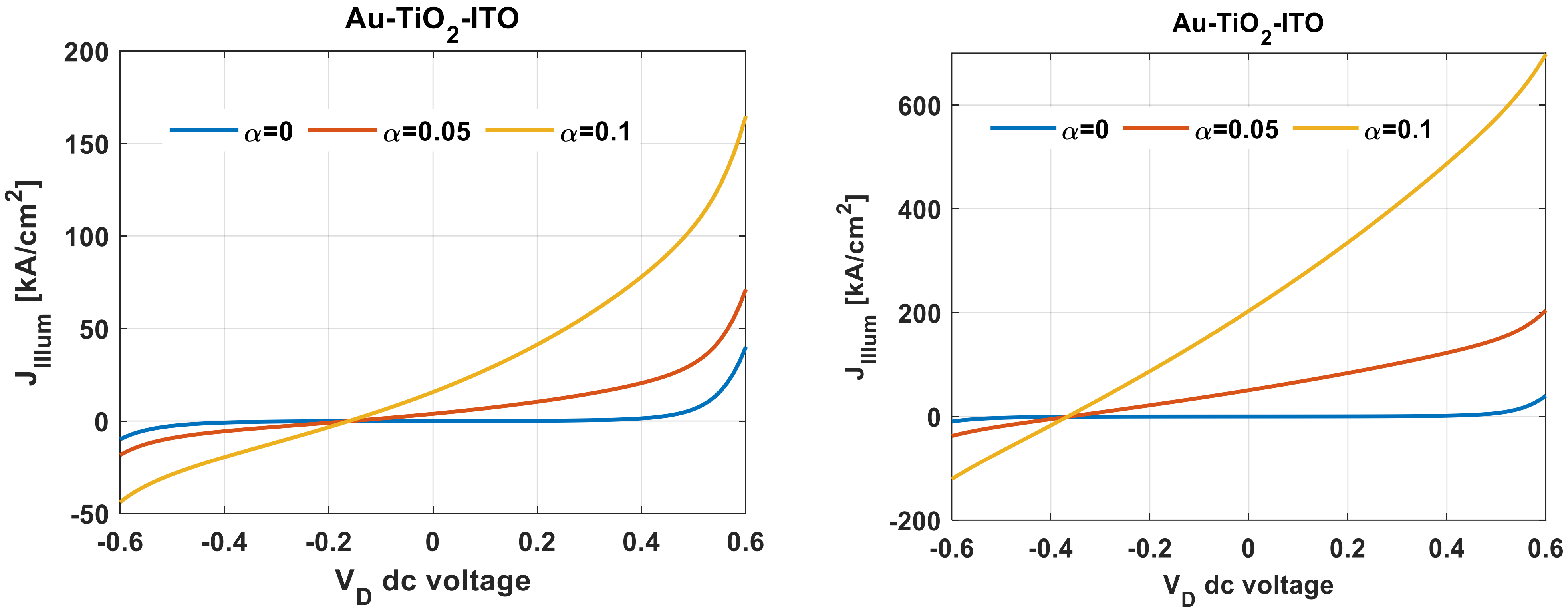


Figure 3: (a) Classical Model to account for the ac signal for modulating the Fermi level on one side of the junction; (b) Semiclassical Model of an electron locates at multitude virtual states of energies with related probabily amplitude as it absorbs or emits photons [2].



Au-TiO2-ITO
α=0
α=0.05
α=0.1
J_Illum [kA/cm2]
V_D dc voltage
200
150
100
50
0
-50
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Au-TiO2-ITO
α=0
α=0.05
α=0.1
J_Illum [kA/cm2]
V_D dc voltage
600
400
200
0
-200
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

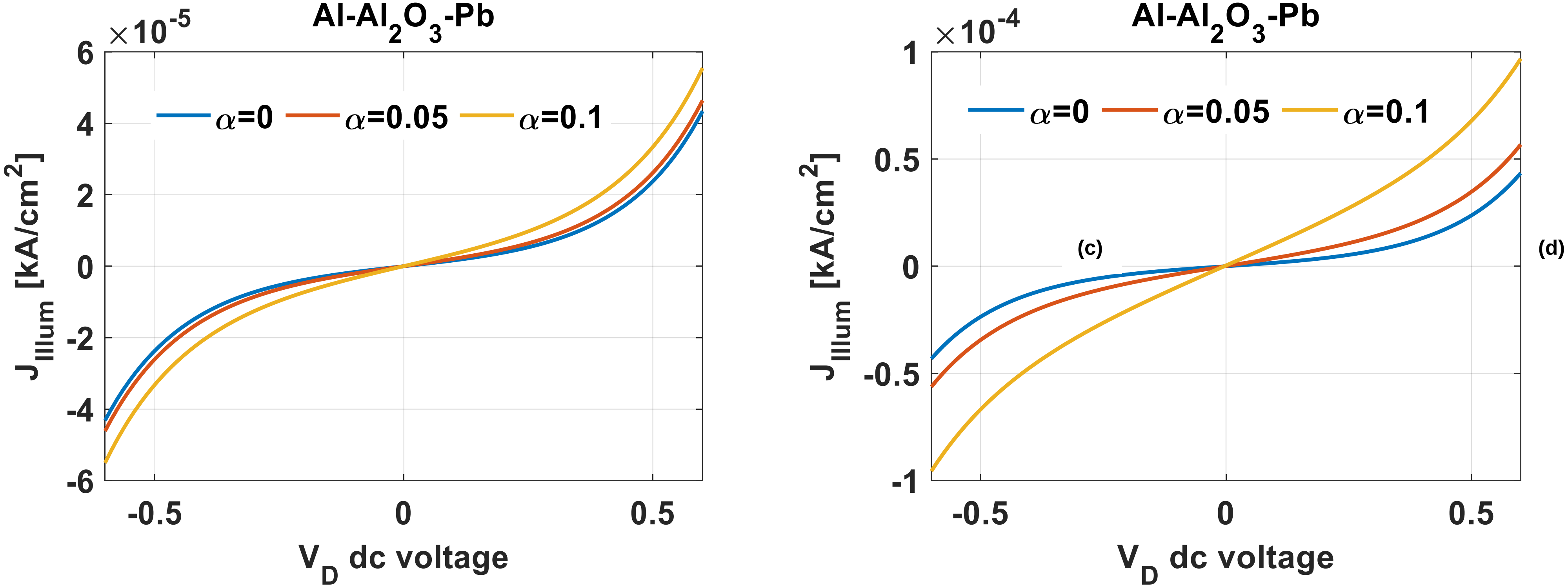


Figure 4: Quantum mechanical approach: Illuminated $I-V$ Curve with the insulator thickness of 2 nm. (a) MIM Au-TiO_2-ITO photodiode illuminated by IR laser with wavelength of 1 um; (b) MIM Au-TiO_2-ITO photodiode illuminated by green laser with wavelength of 550 nm; (c) MIM Al-Al_2O_3-Pb photodiode illuminated by IR laser with wavelength of 1 um; (d) MIM Al-Al_2O_3-Pb photodiode illuminated by green laser with wavelength of 550 nm (α=0 for dark current). $\alpha = \frac{eV_\omega}{\hbar\omega}$; $\alpha = 0$ represents the dark current case.

Efficiency

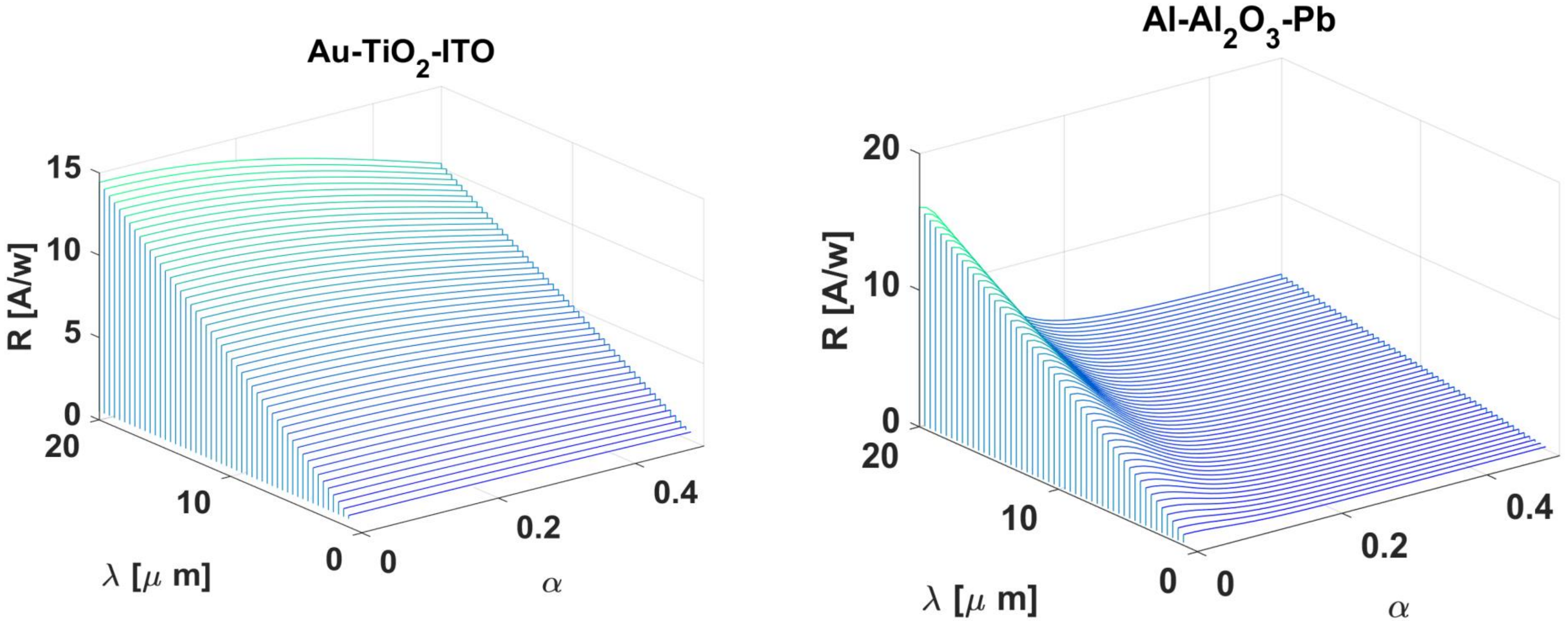


Figure 5: Current-responsivity of MIM diodes in weak radiation field. (a) MIM Au-TiO_2-ITO nanorod; (b) MIM Al-Al_2O_3-Pb nanorod.

Conclusion

The research will be significant to understand the quantum mechanics and the photon-assisted tunneling (PAT) effect in the novel structure [3]. The MIM photodiodes have good applications for ultrafast photon detections due to its good responsivity from microwave to infrared (IR) regime. The efficiency for solar spectrum rectification is a new area and still in its infancy. We will perform new method by applying the black body radiation to calculate the efficiencies of energy harvesting. The electromagnetic field enhancement in the insulating gap region enhances quantum tunneling current, which makes the MIM a large potential for application of optical frequencies rectification.

Reference

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