Enhanced absorption in the Au layer results in increased photocurrent. For comparison purposes, FDTD simulation results are used to calculate the absorption enhancement inside the Au layer due to NPs [Fig. 5(b)]. There is considerable similarity between the resonant behavior of the responsivity ratio [inset of Fig. 5(a)] and the computed absorption enhancement [Fig. 5(b)]. The experimental enhancement peak is red-shifted about 100 nm compared to simulation results. We attribute this shift to possible variation of dielectric properties of the experimental layers from literature values. In addition, surface roughness is neglected in the simulations that could affect the peak location.

Current-voltage measurements of the proposed device are performed under 1 sun solar simulator illumination. V_{OC} is measured to be 40 mV, and I_{SC} is 5 pA. Low photocurrent is attributed to thickness of insulator (HfO_2) layer in the bottom MIM junction. Insulator thickness and the junction quality can be further optimized to increase I_{SC}. The overall conversion efficiency is comparable to a recent proof-of-concept demonstration [4], where the measurements of the MIM device were done under focused helium-neon laser (633 nm) illumination in Kretschmann arrangement.

For our MIM configuration and NP size, the measured responsivity of the device drops below the noise level of the measurement system in the 400 nm - 500 nm wavelength range, which is not very accurately modeled in our simulation. A similar effect was observed by several groups for metal nanostructures on semiconductor absorbers [15, 16]. In such a structure two main electric field components arise: forward scattered field and directly transmitted field. At wavelengths shorter than the resonance wavelength of the metal nanoparticles, the phase difference between these two field components cause partially destructive interference, resulting in a decrease in the photocurrent [15, 16]. The portion of the incident light absorbed inside the NPs can also be considered to be lost since the hot carriers generated therein cannot contribute to the photocurrent due to the relatively thick (10 nm) insulation layer between the NP and the bottom MIM.

4. Conclusion

We demonstrate a new plasmonically enhanced hot electron based photovoltaic device where we separately form the hot electron collection and the plasmon excitation MIM junctions. We exploit resonant characteristics of Au nanoparticles to achieve high field localization in the MIM PV device. Au nanoparticles excite LSP modes and propagating surface plasmon modes, resulting in more than 7 fold enhancement in the short circuit current at the resonance wavelength. The simple planar MIM structure and use of chemically synthesized nanoparticles for plasmon excitation make this device promising for large area fabrication. We also show that plasmon excitation structures can be introduced without modifying the tunneling (rectifying) MIM junction. This gives additional degrees of freedom to optimize the electrical and optical properties of the MIM hot electron PV device. Different resonant structures, e.g. anti-reflection coatings, photonic crystals and cavities, and plasmonic structures, can be incorporated on any planar rectifying MIM junction with desired asymmetry and tunneling properties. Further studies can reveal a path for very low cost and sufficiently efficient photovoltaic cells.

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