Mid-Infrared Energy Harvesting and Conversion Using Rectifying Hyperbolic Metamaterials

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In this talk, we will present a new concept of broadband and wide-angle mid-infrared energy harvesting and conversion technique using nanopatterned hyperbolic metamaterials (HMMs), formed by periodic arrays of dissimilar plasmonic metals separated by a sub-nanometre tunnel barrier (i.e. insulating dielectrics). The exotic slowlight modes in a nanopatterned HMM can efficiently trap the incident radiation in massively-parallel, asymmetric metal-insulator-metal (MIM) tunnel junctions, where the ultrafast optical rectification induced by the photon-assisted tunneling will lead to a highly proficient photon-to-electron conversion, with photoresponsivity orders of magnitude larger than current rectifying nanoantenna (i.e. rectenna) and lumped-element devices.

We have theoretically investigated the performance of the proposed HMM-based rectifying devices, considering the interaction of electromagnetic radiation and nonlinear quantum transports in Ag- Nb_2O_5-Cu MIM tunnel junctions that form the infrared HMM. The HMM is micromachined to have periodic air trenches that provide an interesting zero-group-velocity band, trapping and absorbing the incoming infrared irradiation. Our theoretical results show that a high zero-bias responsivity (~50 mA/W) at wavelengths around $4\,\mu m$ in a wide incident angle rang. Further, by designing the HMM-based nanostructures, the superposition of several slow-wave modes may be achieved, rendering a broadband and efficient infrared-to-dc conversion, spanning from 3 um to 6 um. We have compared the performance of this HMM-based devices with conventional infrared nano-rectennas, and found that the prosed technique can provides much higher responsivity and broader bandwidth than those lumped-element devices (typically in the range of 0.01-1 mA/W). Our results could have an impact on future infrared emissive energy harvesters and wholly plasmonic photodetectors.