High-Performance Infrared Nano-Rectennas Using New Photonic Nanostructures and 2D Materials

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In the radio frequency (RF) and microwave spectra, direct rectification of electromagnetic radiation using antennas loaded with nonlinear devices (rectennas) has been a mature technique for wirelessly transferring power. It has been demonstrated that the RF-to-dc conversion efficiency can be greater than 90 % .[1] Scaling the large-scale antennas to micro/nano-antennas loaded with metal-insulator-metal (MIM) tunneling diodes could enable ultrafast rectification of infrared and visible light. So far, several research groups have reported that nano-antennas hold the potential for harvesting solar and infrared emissive energy.[2] Moreover, the plasmonic resonance and the local field enhancement in nanostructured metals may further boost the optical nonlinearity induced by tunneling plasmons in a MIM junction. However, the reported responsivity (or external quantum efficiency) in the state-of-the-art nano-rectennas is far from the mA/W level, which in turn leads to conversion efficiency less than 1 %.[3]

In this talk, we will discuss MIM nanodiodes tailored to the resonant dipole antenna (RDA) and the broadband log-period tooth antenna (LPDA). Further, we will propose the nanopatterned hyperbolic metamaterials (HMMs) that can efficiently absorb a broad range of incident infrared radiation. The slow-light modes induced in such HMM nanostructure may fully couple the incident infrared radiation into the massively parallel MIM junctions and efficiently rectify it into the dc current. We will present optimal designs of nano-rectenna and HMM, which were obtained from the full-wave electromagnetic simulation, and will propose venues for the experimental realization of such infrared devices for applications in zero-power, cooling-free photodetection and emissive energy harvesting. We will also report characteristics of MIM tunneling nanodiodes based on high-quality, atomically-thin 2D oxides (e.g., 2D TiO_2, HfO_2, and Ta_2O_5) that were prepared by a novel thermal oxidation method.

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[2] S. J. Byrnes, R. Blanchard, and F. Capasso, “Harvesting renewable energy from Earth’s mid-infrared emissions," Proc. Nat. Acad. Sci., vol. 111, pp. 3927-3932, 2014.

[3] E. Briones, J. Alda, and F. J. González, “Conversion efficiency of broad-band rectennas for solar energy harvesting applications,” Opt. Express, vol. 21, pp. 412-418, 2013.