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Vacuum radiometry of an infrared nanoantenna-coupled tunnel diode rectenna

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***Abstract*— We examine the vacuum infrared photoresponse of a large-area nanoantenna-coupled tunnel diode rectenna resulting from thermal radiation from a temperature controlled heater. The measured infrared photocurrent is obtained as a function of the source temperature and the sample distance and view factor. The far-field radiation conversion is examined using standard radiometric techniques and correlated with the rectified current response.**

Keywords—infrared rectenna; energy-harvesting; frequency selective surface; tunneling diode, rectification; radiometry

I. Introduction

Radiant energy recovery from a low-grade heat source requires large-area efficient conversion of infrared radiation into electrical power [1]. Direct rectification of infrared radiation by means of an antenna-coupled tunnel diode, called a rectenna, has been proposed for energy harvesting applications [1,2]. In this process, infrared radiation from a thermal source is confined and enhanced in a direct tunnel diode and the resulting displacement current is rectified

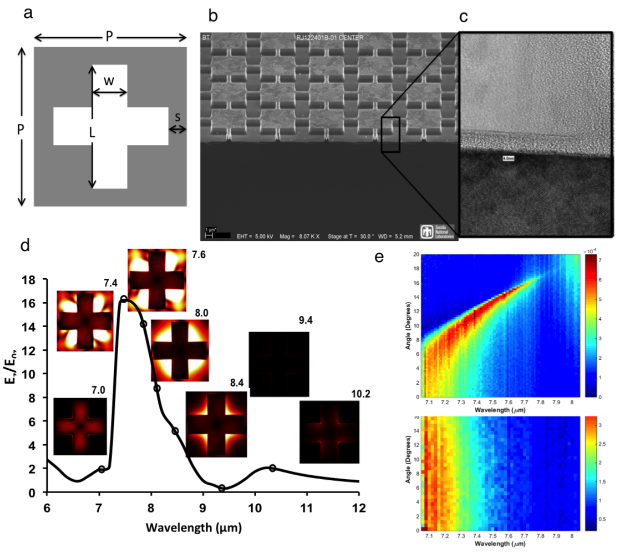

Fig. 1: Fabricated 2D infrared nanoantenna-coupled tunnel diode and its measured photoresponse. (a). Schematic of cross-dipole antenna surface. (b) SEM of large are tunnel diode. (c) HR-TEM of thin (3.5 nm) MOS ytunnel diode. (d) Field concentration plot and (e) measured photoresponse for TM (upper)_ and TE (lower) polarization. See reference [3].

creating a measureable photocurrent. Source temperature, emissivity and radiometric view factors based on the separation and finite size for thermal source emitter and receiver determine available power for conversion.

Previously, we have demonstrated infrared photoresponse in a large-area nanoantenna-coupled metal-oxide-semiconductor (MOS) tunnel diode under coherent infrared quantum cascade laser illumination [2,3]. Figure 1 shows a two dimensional large area tunnel diode fabricated using CMOS fabrication techniques. The oxide tunnel barrier is 3.0-3.5 nm and was chosen to allow for direct tunneling from metal to semiconductor and vice versa. The cross-dipole nanoantenna integrated tunnel diode response under infrared illumination is shown via simulation to enhance the transverse electric field in the tunnel gap leading to enhanced measured infrared photocurrent shown in Fig. 1d and Fig. 1e. Both TE and TM photocurrent signals are found at roughly the design wavelength of 7.3 microns. The large resonant increase in photoresponse has been attributed to photon-enhanced tunneling due to high transverse electric field concentration in the tunnel oxide at resonance.

In this talk, we will examine the photoresponse of a large-area rectenna under irradiation from a thermal source in a vacuum microradiometric experiment. The measured photoresponse and power generation will be examined and discussed.

II. Experiment

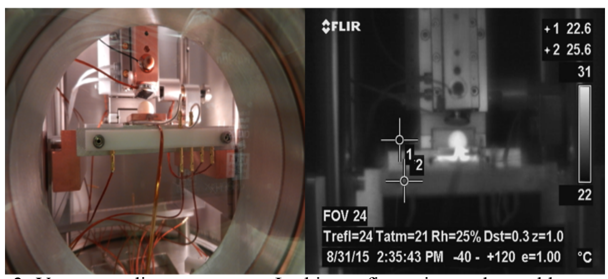

Fig. 2: Vacuum radiometry setup. In this configuration, a thermal heater under a ceramic ball is the thermal source. The rectenna is mounted on a thermally isolated precision stage. The right figure shows the FLIR image of the heated ceramic ball and cool dark rectenna on the stage.

The experimental performance of the nanoantenna-coupled diode illuminated by an incoherent thermal source is needed for estimates of direct power conversion efficiency. The radiometric response of our one and two dimensional nanoantenna-coupled tunnel diode rectenna are measured in the vacuum microradiometry setup. In fig. 2 is shown the microradiometry setup, a thermal source with high emissivity and temperature control is used to illuminate the large-area rectenna in vacuum. The rectenna is mounted on a precision stage that allows for rectenna to be moved from the near-field to far-field of the thermal source. The measured rectenna photocurrent at zero (short-circuit) and non-zero bias is measured as a function of distance and source temperature. Far-field maps of the current-voltage-temperature and conductance-voltage-temperature will be presented and the power conversion efficiency will be discussed. Fast transient effects are observed in the photoresponse and are seen as indication of a fast radiative response followed by slow thermal decay to a new steady-state quasi-equilibrium.

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