Ultrafast Electronic Readout from a Plasmonic Bolometer: Hot Electron Dynamics and Polarization Imaging Applications

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***Abstract*—We have developed a grating-based plasmonic bolometer that features an optoelectronic behavior that is enhanced by plasmonic losses. In our system, optically-induced surface plasmons interact with conduction electrons in the metal, resulting in an increase in electron scattering. Thus, incident electromagnetic radiation induces a detectable change in resistance. Our ultrafast measurements show that these scattering processes occur on extremely short timescales, indicating that these detectors may prove useful for monitoring fast processes. As seen both in our simulations and measurements, the wavelength response of our device is strongly dependent on the physical dimensions of the metal grating and thus tunable in a wide range. Additionally, the polarization-dependent plasmonic response can be utilized for polarization imaging applications without polarization optics.**

I. Introduction

PLASMONIC nanostructures are used successfully for a variety of sensing applications[1-4]. While promising, these diverse applications are limited by the cost and complexity of optical detection schemes required to monitor plasmonic responses[5]. Importantly, they also all face the challenge of resistive losses that are inherent in any free-electron based system[6,7]. Recently however, these thermal losses and the associated localized heating have attracted attention as a useful consequence of surface plasmons in metals[8,9,10]. It was also shown that the introduction of surface plasmons can lead to a change in a bias current passed through the plasmonic metal nanostructure itself[11]. We show that these effects can be used for an all-electronic readout of plasmonic activity, thus greatly simplifying and reducing the cost of plasmonic systems[12,13].

II. Results

This is achieved by leveraging the scattering and subsequent thermalization of plasmonically induced hot electrons within an applied bias current in a metal nanograting shown in Fig.1a. This offers a novel approach for direct electronic readout to determine light properties including polarization and wavelength, which is currently only accessible using complex optical systems[14]. We demonstrate direct polarization imaging (shown in Fig.1b) in a fully-integrated CMOS compatible plasmonic detector by monitoring the resistance changes in the nanogratings. Furthermore, we show that such a detector has a response time governed by the ultrafast scattering processes involved in the relaxation of the plasmonically excited hot electrons[15].

When a DC bias current is applied through the nanograting, the fermi level of free electrons is subsequently tilted and asymmetric as shown in Fig.1c, resulting in a shifted electron distribution along the applied current (x-direction) in the k-space[16]. At room temperature, energy of hot electrons generated by plasmon is quickly redistributed among lower-energy electrons via electron-electron scattering[17,18]. These

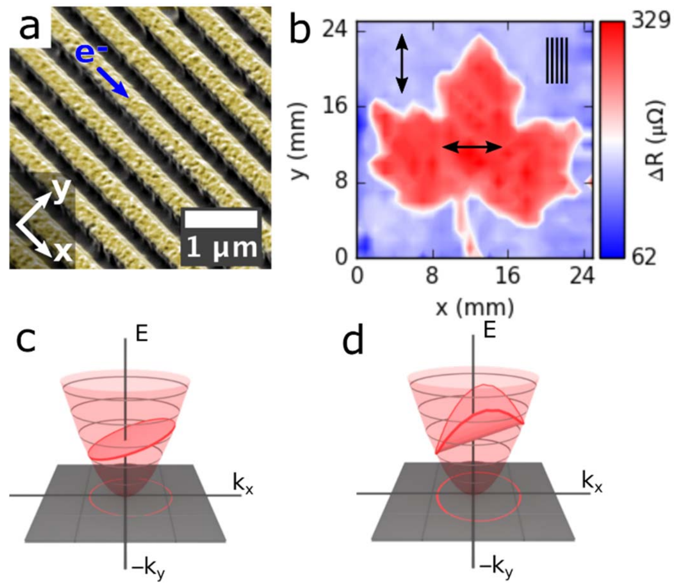

Fig. 1. (a) SEM image of the metal nano-grating. The direction of the bias current is indicated by the blue arrow. (b) Polarization image of a maple leaf mask. The resistance change is color coded. Red (blue) corresponds to a large (small) resistance change for EM-radiation polarized perpendicular (parallel) to the grating. (c-d) Dispersion relations of the free electron gas in k-space. (c) the Fermi level indicated by the oblique red surface within the energy paraboloid is tilted in the k_x-direction due to the applied bias current. (d) Plasmonically excited hot electrons lead to higher occupied states indicated by the curved wings in the k_y-direction of the red oblique surface.

lower-energy electrons with reduced velocities then interact with phonons and in thermal equilibrium electron-phonon scattering primarily dominates the resistance in metals[19]. When electromagnetic radiation is introduced into the system, photons interact directly and indirectly with the electrons in the metal, which leads to hot electron generation[20,21]. However, in the case of plasmonic excitation, the generation of hot electrons has a well-defined dependence on the k-vector of the incident light[22], forming curved wings in the Fermi level shown in Fig.1d. Due to the asymmetry of the shifted fermi level and the positive average momentum of free electrons, surface plasmon relaxation requires additional negative momentums which are generated from electron-phonon scattering processes. And as these negative momentums are in the opposite direction of the current, a finite, measurable resistance in the applied current is induced. We want to emphasize that this plasmon-induced resistance strongly depends on the k-vector of the incident light, thus offers a novel approach to convert the light properties into electronic signals.

III. Summary

The electronic readout of plasmonic interaction greatly simplifies plasmon-based sensing and detection schemes by eliminating the need for highly optimized optical systems, simultaneously reducing costs, and yielding more reproducible and reliable data[23]. And owing to the sub-picosecond timescales of plasmon relaxation, it's a promising candidate for identifying ultrafast electronic temporal dynamics and designing ultra-broad bandwidth communication devices[24]. Finally, because the materials, structural dimensions, and measurement tools involved are entirely compatible with current CMOS integrated circuit technology, this approach offers a means to realize truly on-chip plasmonic devices, thus enabling broader access to plasmonic technologies[25,26,27].

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