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Ultraviolet light emission from resonant gold dipole antennas in air illuminated with intense sub-picosecond terahertz transients

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Abstract— We experimentally show that metallic dipole antennas emit ultraviolet radiation when illuminated with ultrashort high-power terahertz pulses due to ultrafast electron field emission from the metal and consecutive ionization and excitation of atmospheric gas molecules.

I. INTRODUCTION

THE development of high power ultrafast terahertz (THz) table-top sources [1] has opened the door to a rapid progress in nonlinear terahertz optics. Nonlinear THz phenomena have been demonstrated for plasmas, various gases, liquids, and solid-state materials [2]. Especially THz nonlinear optics of semiconductor materials has been a widely explored area. Effects such as intervalley scattering [3], impact ionization [4], self phase modulation [5] or high harmonic generation [6] have been demonstrated. But so far, according to our knowledge, very little progress has been achieved on understanding the interaction of strong THz pulses with metals. Here we present one of the first demonstrations of extreme nonlinear interactions between THz waves and a metallic system.

II. RESULTS

Resonant THz-frequency dipole antennas are fabricated on a high resistivity silicon substrate by a standard UV lithography process after full wave 3D numerical simulations of the resonant properties of the antennas. The structure design was optimized to maximize the field enhancement at the resonant frequency. Figure 1(a) shows the result of optimization for a frequency of 0.6 THz, while Fig.1(b) shows the spatial distribution of the THz electric field amplitude at 0.6 THz in the plane of the antenna. The field has a dipole-type spatial distribution and a field enhancement factor over 25 is reached at the tips of the antenna.

We make the surprising observation that the resonant dipole antenna samples emit characteristic UV light when exposed to strong field THz transients. Single-cycle terahertz transients with frequency spanning from 0.1 to 2.5 THz and peak electric field strength >300 kV/cm are obtained by optical rectification in a tilted-wavefront phase-matching configuration. In a separate experiment [7] we have shown that the emission spectrum is composed of a series of spectrally narrow lines situated between 300 nm and 400 nm, clearly identifying the THz-induced photoluminescence as originating from the second positive band of molecular nitrogen.

Figure 1(c) shows the intensity of the UV light measured by the PMT tube with a 10 nm wide 340 nm bandpass filter in a two THz pulse experiment. When two THz pulses arrive at the

resonant antenna simultaneously, strong and highly nonlinear enhancement of UV emission is clearly visible. As the THz-THz time delay increases, UV emission decreases and oscillates a frequency of 0.59 THz, which agrees very well with the designed maximum field enhancement frequency.

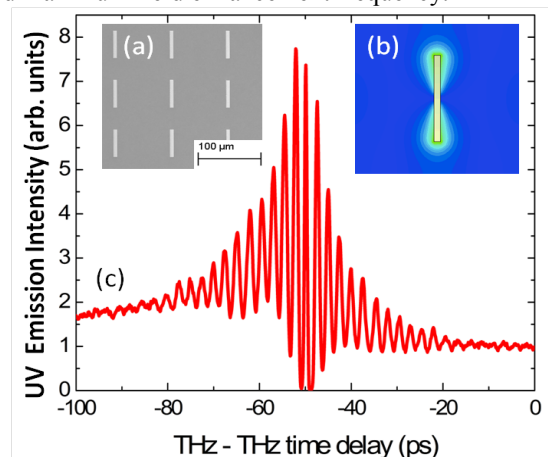


Fig. 1. (a) SEM images of resonant THz antennas for efficient UV light emission. (b) 3D simulation of the THz electric field distribution at the resonant frequency of 0.6 THz. (c) UV emission intensity as a function of THz-THz time delay.

III. SUMMARY

We attribute observed effect to ultrafast electron field emission from the metal and consecutive ionization and excitation of the gas molecules surrounding the antennas. The resonant metal structure acts as the source of electrons and also provides nearfield enhancement to the terahertz electric. The emitted electrons are subsequently accelerated in the electric field and reach energies as high as 100 eV. Such energetic electrons can ionize or excite molecules of the gas surrounding the antenna. During the return to the ground state the molecules can emit photons with energies given by the difference of the energy levels between the excited states and the ground state.

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