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High harmonic generation from a degenerate plasma

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Abstract—Plane electromagnetic waves can interact strongly with a spatially confined degenerate plasma in a thin layer of transparent conductive oxide at its epsilon-near-zero wavelength. Using high mobility CdO:In conductive oxide, up to 9th harmonic of the fundamental pump wave was observed. This approach offers great flexibility for input laser wavelengths.

Keywords—epsilon-near-zero, degenerate plasma, harmonic generation, conductive oxide.

I. INTRODUCTION

High harmonic generation has been used to generate extreme ultra-violet light sources to probe fast electron dynamics in the attosecond time scale[1]. Harmonic orders as high as thousands have been demonstrated in high pressure gas based on the mechanism that electrons produced by tunnel ionizations are driven more strongly by the external electromagnetic field than the coulomb field of its parent ion[2]. Similarly, electrons in doped semiconductors or transparent conductive oxides can be driven by laser field and may interact or scatter from the ionic fields in the crystal to create highly nonlinear electronic motions and hence producing harmonic fields efficiently. Because of high electron and ion densities in solid, and the ions are essentially locked in a lattice space, the interaction dynamics can be quite different from gaseous media. Indeed, high harmonic generation from graphene[3], ZnO[4], MoS_2[5] was observed. In this paper, we explore high doped semiconductor materials where the ionic fields are screened, and electrons are largely free. The intensity required to produce significant nonlinear response is lower. For the CdO:In, 9th harmonic was observed using intensities of 10GW/cm^2 rather than TW/cm^2.

II. RESULTS

The sample under studied is a 75nm thick In doped CdO film on MgO crystal substrate with a carrier density of 2.8×10^{20} cm^{-3} and an electron mobility of 200 cm^{2}V^{-1}s^{-1}. The sample is coated with 200nm thick Au and the laser field is coupled to the sample from the substrate side to achieve the maximum field enhancement. This structure possesses a mode which can be excited with a p-polarized 2.08μm femtosecond laser pulse with near zero reflectivity as shown in Figure 1.

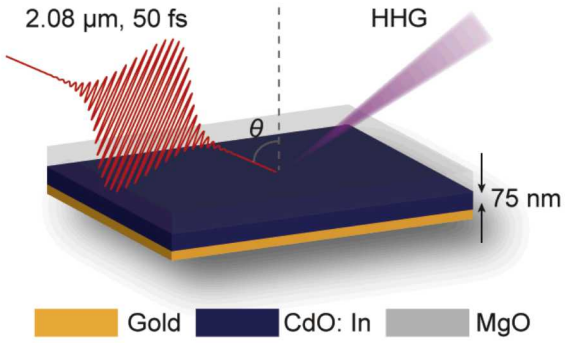

Figure 1. Schematic illustration of the excitation geometry of the sample.

The pump and generated harmonic radiations in the specular reflection direction of the pump radiation. The harmonic radiation are separated and filtered before being dispersed by a spectrometer to produce a spectrum shown in Figure 2.

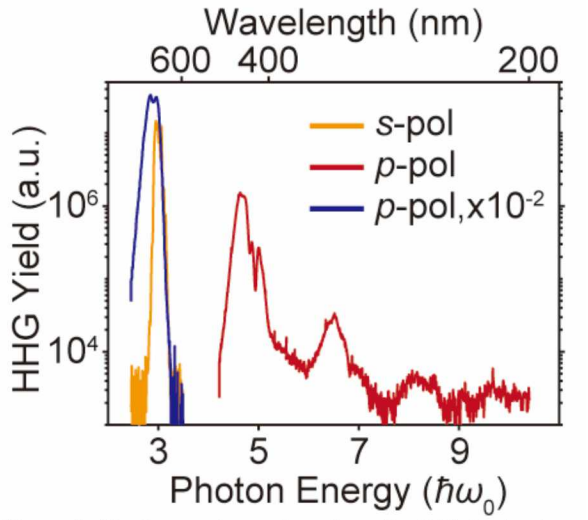

Figure 2. The harmonic spectrum from the CdO:In structure excited by 2.08μm at an intensity of 11.3 GW/cm^2.

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Figure 2 shows the 3rd harmonic wave generated from p-polarized pump is two orders of magnitude stronger than S-polarized, indicating that the free electrons dominates the nonlinear response. Furthermore, the harmonic fields frequencies are red shifted and broadened compared to S-polarized exciting field. Using a simple two electron model[6] to account for the laser heating effects of the electrons which causes an increase in the averaged effective mass can qualitatively explain the red shift behavior. A more sophisticated dynamical model is needed for quantitative agreement.

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