Nanostructured Interdigitated Electrodes for Microlensless Photoconductive Terahertz Emitters

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***Abstract*—A new design for interdigitated photoconductive antenna (iPCA) has been studied. Using the plasmonic electrode techniques for photoconductive THz sources, we were able to design this new electrode designs for iPCA, which does not require microlens focusing and is much easier to fabricate in comparison to other alternatives of microlensless iPCAs.**

I. INTRODUCTION

PHOTOCONDUCTIVE technique of terahertz (THz) generation works on switching the conductivity of the material via sub-picosecond optical pulse excitation. It is one of the most popular techniques to generate THz radiation at room temperature. Electric field of the emitted THz pulse should scale linearly with the pulse energy of the optical excitation but saturates at higher optical excitation density (> 0.2mJ/cm^2) which degrads its optical to THz conversion efficiency and restrict THz electric field[1]. To overcome the saturation problem, large area THz emitters are good choice, as because of larger excitation area more optical power can be used without emitter going in the saturation region. Interdigitated photoconductive antenna (iPCA) have been proved efficient and also they do not require very high bias[2]. But due to its design, it either requires microlens focusing or covering of alternate active regions. This makes iPCA fabrication cost expensive.

Gold grating lines of sub-wavelength width (~200 nm) can couple incident light (800 nm) more efficiently into the substrate[3]. If these grating lines are attached to the electrodes (plasmonic electrode), more number of photo-generated charge carriers can reach the electrodes in sub picosecond time and hence enhancement in photoconductive THz emission is observed [4]. Here we have fabricated three photoconductive devices on semi insulating (SI) GaAs, (1) simple PCA device having line edge electrodes (LE-PCA) with a gap of 5 µm for the active area of the emitter, (2) plasmonic PCA (P-PCA) which has grating like structure with period of 400 nm, attached to the electrodes on both sides of the active area, and (3) iPCA having asymmetrical plasmonic electrodes (AP-iPCA) in such way that each alternate active area have plasmonic electrodes on both sides, whereas remaining alternate active areas have simple line edge electrodes on both sides. All three emitter structures are shown in figure 1.

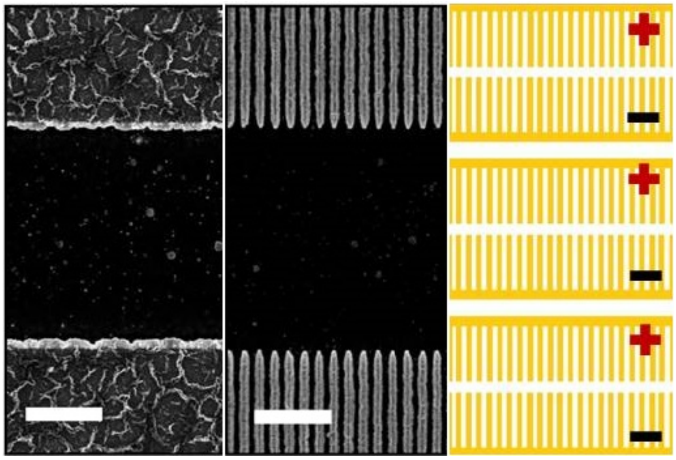

Fig. 1. Left to right, SEM images of line edge (LE) PCA and plasmonic (P) PCA respectively, scale bar is 2 µm. Right most figure is schematic diagram of asymmetric plasmonic (AP) iPCA. Electron beam lithography was used to fabricate the devices.

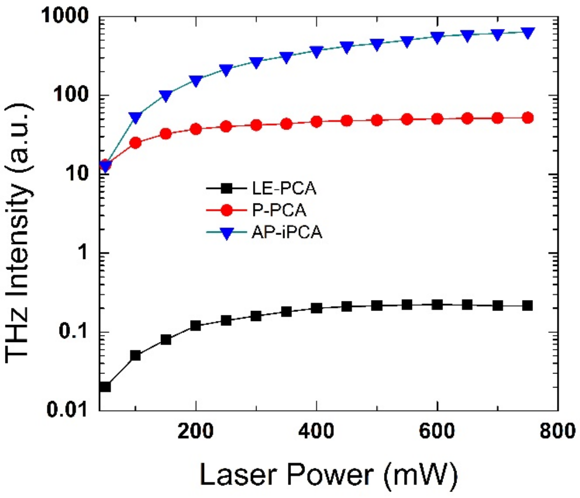

Fig. 2. THz signal recorded from bolometer for three electrodes designs at different optical power excitation. Optical excitation spot for LE-PCA and P-PCA was ~ 10 µm, and for AP-iPCA it was ~ 350 µm. 5 V bias was applied on all three emitters as all of them have same electrode gap of 5 µm.

Since it is expected that the active regions with plasmonic electrodes on both sides will emit more THz than that of usual line edge electrodes. Therefore even after destructive interference, THz emitted from line edge electrode active regions will not be able to completely cancel out THz emitted from plasmonic electrode active regions. Larger the difference between THz emission efficiencies of plasmonic and non plasmonic active regions, better the performance of the AP-iPCA emitter will be.

II. RESULTS

Three THz photoconductive emitters fabricated on SI-GaAs were pumped with ~100 fs, wavelength centered around 800 nm laser pulses with the repetition rate of 76 MHz. Polarization of the incident optical pulse was such that its electric field direction was perpendicular to the grating lines in the plasmonic electrodes, i.e. in the horizontal direction relative to the figure 1. A liquid helium cooled Bolometer was used to compare their THz emission efficiency. Results are shown in figure 2.

As expected P-PCA was giving more than 2 orders of THz power in comparison to usual LE-PCA. As already explained, this is due to two reasons; 1.) better inward coupling of incident optical pulse into the SI-GaAs substrate due to gold grating lines, which will result in more number of photo-generated charge carriers and 2.) more number of photo-excited carriers generated (below the grating lines) can reach to the electrodes in subpicosecond time. This is probably playing a major role in the emitter efficiency enhancement. Since for these two emitters incident optical pulse was tightly focused and hence both of these emitters were almost fully saturated at higher optical excitations (> 200 mW) due to screening effects.

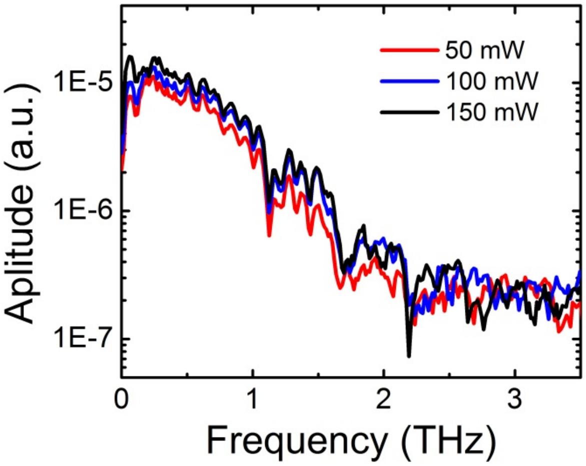

Fig. 3. FFT plot of THz pulses emitted from AP-iPCA at different optical excitation powers.

Our new iPCA design AP-iPCA has much larger area for photo excitation and hence excitation on ~ 350 μm diameter spot was done. AP-iPCA has shown increment in THz emission even up to 750 mW optical excitation. At highest optical excitation power AP-iPCA was efficient by more than three orders in comparison to usual single active region LE-PCA and by an order of in comparison to plasmonic PCA with single active region. Also, it does not require any microlens focusing to avoid destructive interference.

To see the frequency components present in the emitted THz pulse from AP-iPCA, THz pulse was recorded using standard electro optical sampling. FFT of the THz pulse recorded in time domain is shown in figure 3.

III. SUMMARY

With the help of plasmonic electrode designs for photoconductive THz emitters, a new plasmonic electrode for interdigited photoconductive antenna have been developed and tested. It is more than 3 orders of more efficient than usual PCA and almost an order of magnitude more efficient than plasmonic PCA at 750 mW optical excitation. Also it does not require any microlens focusing. Such easy to fabricate large area emitter will be very effective for optical excitations with pulse energies in μJ to mJ.

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