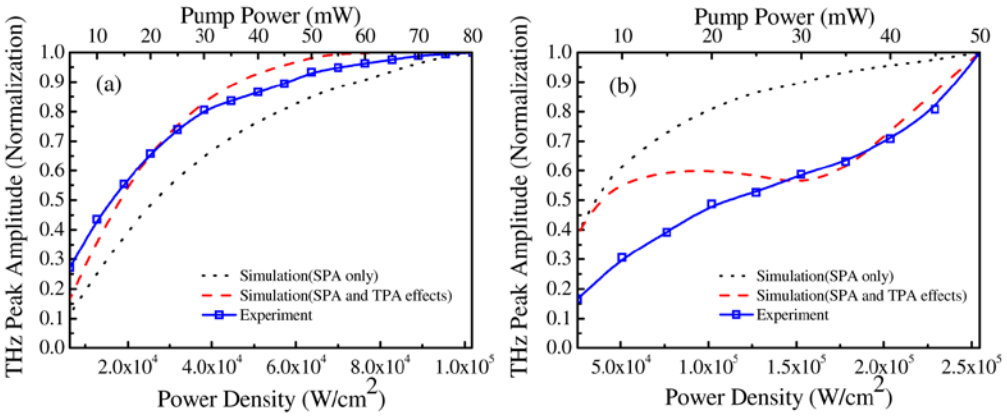

Fig. 5. Pump power dependencies of the THz peak amplitude. (a) The laser beam spot size is 10 μm. (b) The laser beam spot size is 5 μm.

Previous theoretical studies show that the local electric field oscillates if the generated carrier densities exceed 10^{20} cm^{-3} in LT-GaAs. Further, the oscillation frequency increases monotonically with the carrier density. This can be explained by the interplay between the bias field and the polarization induced in the PC [14,21]. The free carriers are initially accelerated and the polarization is generated to screen the bias field. While the bias field is canceled by the polarization, the momentum of free carriers is not zero and free carriers still drift to increase the polarization. The direction of the local field is reversed and the carriers are accelerated to the backward direction. As a result, the local electric field oscillates. Therefore the central frequency of the THz radiation generated should increase with the carrier density. However, it is difficult to observe this phenomenon experimentally because the carrier density at the bottom of the conduction band is limited to about 5×10^{18} cm^{-3}. Further increase of generated carrier density can be achieved by TPA effect as shown in this work. This hints at the possibility of generating higher-frequency THz radiation from PC antennas.

4. Conclusions

In this work, feasibility of enhancing THz radiation power due to TPA induced photo-carrier in PC antennas is studied theoretically and experimentally. Features of the THz waveform associated with SPA and TPA are clearly identified for the first time. At low excitation power densities, TPA actually caused radiated THz power to decrease. When photocurrent due to SPA saturated, however, extra carriers can still be excited to the conduction band by TPA, if the exciting photon density is sufficiently high. Experimentally, using the pulse shaping technique, we observed an anomalously increasing radiated power rather than saturation. This is in good agreement with predictions of the theoretical predictions and simulation results. With transform-limited pulses at the PC antenna, TPA effect can be enhanced for higher-power excitation condition. We show that TPA effect can help to break through the limitation of generation of THz radiation power by the PC antenna due to SPA. Besides, possibility of enhancing the high-frequency spectral components of THz radiation by TPA is also discussed.

5. Acknowledgments

This work was financially supported by the various grants of National Science Council Taiwan (R.O.C.) (NSC98-2112-M-110-001-MY3, NSC96-2752-E-009-007-PAE and NSC96-2752-E-009-008-PAE). Sung-Hui Lin now works at the Taiwan Semiconductor Manufacturing Company. The authors would also like to thank Prof. L. Yan of the University of Maryland, Baltimore County for helpful discussions.