THz Emission from Transient Electrical Currents Injected into Semiconductors via Optical Quantum Interference

M. Betz, J-M. Ménard, C. Sames, L. Costa, M. Spasenovic, A.D. Bristow and H. M. van Driel
Department of Physics, University of Toronto, Toronto, M5S-1A7, Canada

***Abstract*—Quantum interference between single and two photon inter-band absorption processes can lead to injection of electrical currents in direct and indirect band gap semiconductors. When the optical excitation occurs through 100 fs optical pulses the transient electrical currents emit THz radiation that can be used as a probe of the ultrafast current dynamics.**

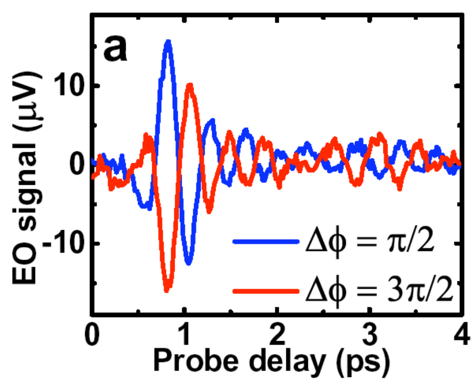
I. Introduction And Background

Coherence control is based on the use of the optical phase of light beams to control the electronic state of matter via quantum interference effects. Several years ago our group and that of our colleagues have shown how one could use quantum interference between the absorption of optical beams to inject electrical and spin currents in semiconductors[1-3]. Such a processes allows one to produce and control transient currents at spatial points and on time scales governed by the optical beam, and not dictated by electrical contacts. In particular, we have shown how interference in the absorption pathways of single photons at frequency 2ω and two photons at frequency ω in either centrosymmetric or non-centrosymmetric cubic semiconductors such as Si or GaAs can lead to electrical current injection. The current injection rate varies as the phase difference between the optical beams and the current directionality can be further controlled via beam polarization. In lower symmetry semiconductors, such as Wurtzite materials or quantum wells, interference between the absorption of orthogonally polarized states of a single beam with photon energy larger than the band gap can also produce electrical currents. When optical pulses with temporal width on the order of a picosecond or less are used, the transient current build-up and decay can lead to emission of THz radiation. This radiation can be used as a probe of details of the current dynamics.

II. Results

Coherently controlled generation of currents in semiconductors is a robust process and not strongly dependent on the properties of the semiconductor. Most of our experiments have involved the use of 150 fs fundamental pulse with wavelength in the 1200-1900 nm range, with the second harmonic beam in the 600-950 nm range. This has allowed us to control currents in direct band gap materials such as CdSe, CdTe, GaAs and InP and even in indirect gap materials such as Si and Ge. The THz emission serves as a signature of the currents and is measured using free space electro-optic sampling techniques with an 830 nm probe pulse. The figure shows a typical trace of the THz emission (electro-optic signal) recorded from a piece of (100) silicon at room temperature following excitation by 1500 and 750 nm pulses. In this case the apparent temporal dynamics are limited by the bandwidth of the electro-optic sampling detector. Nonetheless the results show how the current and THz polarization can be varied with the relative phase of the optical beam pulses.

The emitted THz radiation allows us to probe many aspects of the current generation process including efficiency, polarization properties, temporal dynamics and the role of many body effects. While the efficiency of this source of THz emission is not higher than that of our sources, e.g. based on photoconductive antennas or optical down-conversion, the fact that the THz radiation is dependent on the phase properties of the optical beams might allow one to unique control aspects of THz beams.



References

[1] A. Haché, Y. Kostoulas, R. Atanasov, J.L. Hughes, J.E. Sipe and H. M. van Driel, Observation of Coherently Controlled Photocurrents in Unbiased, Bulk GaAs, Phys. Rev. Lett. **78**, 306 (1997).

[2] M.J. Stevens, A.L. Smirl, R. Bhat, A. Nahmaie, J.Sipe and H.M. van Driel, Quantum Interference Control of Ballistic Pure Spin Currents in Semiconductors, Phys. Rev. Lett. **90**, 136603 (2003).

[3] J. Hübner, W. Rühle, M. Klude, D. Hommel, R.D. R. Bhat, J.E. Sipe and H. M. van Driel, Direct Observation of Optically Injected Spin-Polarized Currents in Semiconductors, Phys. Rev. Lett. **90**, 216601 (2003).

[4] L. Costa, M. Betz, M. Spasenovic, A.D. Bristow and H. M. van Driel, All-optical Injection of ballistic electrical currents in unbiased silicon, Nature Physics, **3**, 632 (2007).

[5] M. Spasenovic, M. Betz, L. Costa, and H. M. van Driel, All-optical coherent control of electrical current in centrosymmetric semiconductors, Phys. Rev. B **77**, 085201 (2008).

978-1-4244-2120-6/08/$25.00 ©IEEE.