The Polarization Dependence of QuIC Injected Photocurrents Reveals Current Injection Tensors

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Abstract: We study current injection tensors of Quantum interference control (QuIC) processes by measuring their dependences on single-polarization rotation. We show that the direction of QuIC photocurrents is determined by the polarization of odd-order optical absorptions.

Quantum Interference Control (QuIC) is the manipulation of a system due to the interference of two independent pathways coupling the same initial and final states. The interference, contributing constructively or destructively to the transition amplitude [1], is effectively a "matter interferometer," where the laser phase is a key control parameter. It has been explored in different systems such as atomic gases, molecular systems, and semiconductors. The QuIC of one- and two- photon absorption (1+2 QuIC) was achieved by A. Haché et al. [1] in bulk unbiased GaAs. The QuIC of two and three- photon absorptions (2+3 QuIC) was achieved by K. Wang et al. [2] in bulk unbiased AlGaAs. In this work, we study the single-polarization dependence of QuIC currents in 1+2 QuIC and 2+3 QuIC with Ohmic-contact AlGaAs devices, as shown in Fig. 1 (c).

The observation of 1+2 QuIC requires phase related fields with a factor of two difference in frequency. This is achieve by generating second harmonic in a 100 µm BBO crystal of a mode-locked laser, which is centered at 1040 nm. The repetition rate of the laser is 250.583 MHz. A prism pair separates the 1040 nm light from its second harmonic spatially. The 520-nm arm of the interferometer was dithered sinusoidally over about λ/4 at 2 KHz for lock- in detection The 1040 nm beam and 1560 nm beam were focused onto the center of four electrodes by a 60X objective. The power of 1040-nm illumination is ∼ 42mW, and the power of 520-nm illumination is ∼ 8mW.

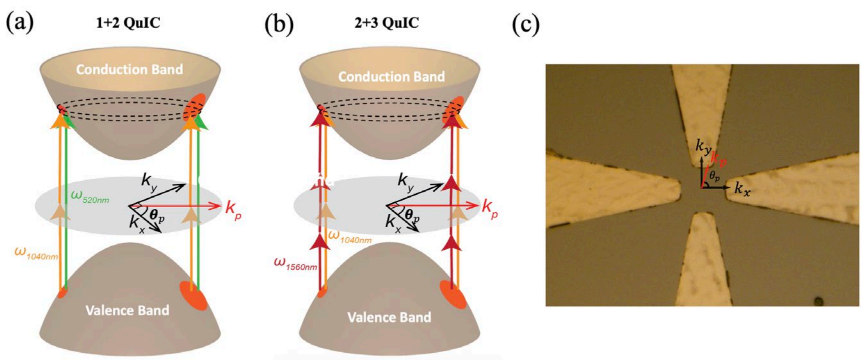

Figure 1. (a) A schematic diagram of the 1+2 QuIC on the band structure of semiconductor. (b) A schematic diagram of the 1+2 QuIC on the band structure of semiconductor. (c) Two pairs of electrodes detect photocurrents flowing in two perpendicular directions. k_x and k_y are aligned to [100] and [010] crystal axis. The polarization of one of the two excitation fields is along k_p and the polarization of the other excitation field is along k_x.

2+3 QuIC requires pulses with a frequency ratio of 3/2, which is not easily achieved using harmonic generation. As an alternative approach, we use a frequency comb that spans the required frequencies producing output at 1040 and 1560 nm [2]. The offset frequency of the comb was measured using the heterodyne beat note produced in a 2f -3f self-referencing interferometer. The offset frequency of the 1040 nm beam and 1560 nm beam were set to be 28 KHz and 20 KHz respectively using a feed-forward scheme. The 1040 nm beam and 1560 nm beam were focused onto the center of four electrodes by a 60X objective. The QuIC photocurrent was detected at 128 KHz with Lock-in Amplifiers.

We measure the photocurrents in 1+2 and 2+3 QuIC signals, shown in Fig. 2, while rotating one of the polarizations with an angular rate of 720 degrees/s. The shaded areas are the variances of polarization dependence scans. The two beams in each QuIC process are both linearly polarized. When one of the polarizations is rotated, the other polarization is across the horizontal electrode pair.

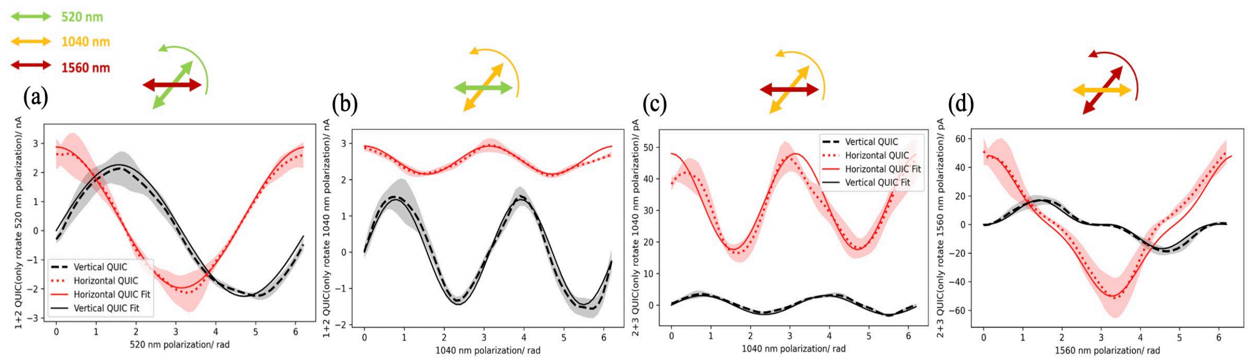

Figure 2. (a) The 1+2 QuIC currents as a function of the polarization angle of the 520 nm beam. (b) The 1+2 QuIC currents as a function of the polarization angle of the 1040 nm beam. (c) The 2+3 QuIC currents as a function of the polarization angle of the 1040 nm OFC. (d) The 2+3 QuIC currents as a function of the polarization angle of the 1560 nm OFC. In these figures, the red dotted curves denote the currents collected by horizontal electrode pair, which are fitted by the red solid curves. The black dashed curves denoted the currents collected by vertical electrode pair, which are fitted by the black solid curves.

Fig. 2 (a) and Fig. 2 (d) show that the 1+2 QuIC current changes sign when the 520 nm polarization rotates by $\boldsymbol{\pi}$ and the 2+3 QuIC current changes sign when the 1560 nm polarization rotates by $\boldsymbol{\pi}$. In other words, the direction of the QuIC currents rotates with the polarization of the odd-order optical absorptions. This has been theoretically predicted [3]. Our result on the 1560-nm polarization dependence of 2+3 QuIC is consistent with the experimental data in [2].

The horizontal 1+2 QuIC when rotating the polarization of 520-nm light can be written as: $I_{1+2}^{horizontal}\left(\theta_p^{520}\right) = \eta_{1+2}^{xxxx}|E_{520}||E_{1040}|^2\cos\left(\theta_p^{520}\right) = \langle xxxx\rangle\cos\left(\theta_p^{520}\right) + c.c.$. The vertical 1+2 QuIC, when rotating the polarization of 520-nm light can be written as: $I_{1+2}^{vertical}\left(\theta_p^{520}\right) = \langle yyyy\rangle\sin\left(\theta_p^{520}\right) + c.c.$. The horizontal 1+2 QuIC when rotating the polarization of 1040-nm light can be written as: $I_{1+2}^{horizontal}\left(\theta_p^{1040}\right) = \langle xxxx\rangle\cos^2\left(\theta_p^{1040}\right) + \langle xyyx\rangle\sin^2\left(\theta_p^{1040}\right) + c.c.$. The vertical 1+2 QuIC, when rotating the polarization of 1040-nm light, can be written as: $I_{1+2}^{vertical}\left(\theta_p^{1040}\right) = 2\langle yyxx\rangle\cos\left(\theta_p^{1040}\right)\sin\left(\theta_p^{1040}\right) + c.c.$.
We fit the experimental data in Fig. 2 (a) and Fig. 2 (b) with the same set of parameters: $\langle xxxx\rangle \approx 2.9\,nA$, $\langle yyxx\rangle \approx 1.1\,nA$, $\langle yxxy\rangle \approx 2.3\,nA$.
The horizontal 2+3 QuIC when rotating the polarization of 1040-nm light can be written as: $I_{2+3}^{horizontal}\left(\theta_p^{1040}\right) = \langle xxxxxx\rangle\cos^2\left(\theta_p^{1040}\right) + \langle xxxxyy\rangle\sin^2\left(\theta_p^{1040}\right) + c.c.$. The vertical 2+3 QuIC, when rotating the polarization of 1040-nm light, can be written as: $I_{2+3}^{vertical}\left(\theta_p^{1040}\right) = 2\langle yxxxyx\rangle\cos\left(\theta_p^{1040}\right)\sin\left(\theta_p^{1040}\right) + c.c.$. The horizontal 2+3 QuIC when rotating the polarization of 1560-nm light can be written as: $I_{2+3}^{horizontal}\left(\theta_p^{1560}\right) = \langle xxxxxx\rangle\cos^3\left(\theta_p^{1560}\right) + \langle xxyyxx\rangle\cos\left(\theta_p^{1560}\right)\sin^2\left(\theta_p^{1560}\right) + c.c.$. The vertical 2+3 QuIC, when rotating the polarization of 1560-nm light, can be written as: $I_{2+3}^{vertical}\left(\theta_p^{1560}\right) = \langle yyyyyy\rangle\sin^3\left(\theta_p^{1560}\right) + 3\langle yxxyxx\rangle\sin\left(\theta_p^{1560}\right)\cos^2\left(\theta_p^{1560}\right) + c.c.$.
We fit the experimental data in Fig. 2 (c) and Fig. 2 (d) with the same set of parameters: $\langle xxxxxx\rangle \approx 48.2\,pA$, $\langle xxxxyy\rangle \approx 16.5\,pA$, $\langle xxyyxx\rangle \approx 7.2\,pA$, $\langle yxxyxx\rangle \approx 2.8\,pA$, $\langle yxxxyx\rangle \approx 1.4\,pA$.

In summary, the polarization dependences of 1+2 and 2+3 QuIC currents has been studied with an Ohmic-contact QuIC device. The direction of 1+2 and 2+3 QuIC currents is determined by the polarization of odd-order optical absorption light. The optical injection tensor elements of 1+2 QuIC and 2+3 QuIC can be obtained by fitting the polarization dependence curves.

References
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