Polarization-Independent Cross-Correlation Using Two-Photon Absorption

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Abstract: We theoretically and experimentally investigate the polarization dependence of two-photon absorption in cross-correlation measurements, and we demonstrate that by fixing one of the input polarization states, the cross-correlation signal becomes independent of the second polarization.

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Optical cross-correlation methods have been proposed for applications including optical sampling, address recognition, demultiplexing and clock recovery. Many techniques for performing optical correlations are polarization-dependent, making them impractical in fiber-based systems. Two-photon absorption (TPA) is a nonlinear process that is simple, inexpensive, sensitive [1], and ultrafast [2]. We show here that TPA can be used to produce a cross-correlation signal that is insensitive to the polarization state of one of the input signals.

For isotropic $\chi^{(3)}$ materials with non-resonant electronic nonlinearities, the photocurrent generated through two-photon absorption can be described by:

$$i_{\mathrm{TPA}} \propto \left\langle |\mathbf{E}(t)|^4 \right\rangle \ , \tag{1}$$

where $\langle \cdot \rangle$ indicates the time-average[1]. Among other things, Eq. 1 predicts that while the nonlinear photocurrent is the same for all linear polarizations, it decreases by $\frac{2}{3}\times$ for circularly polarized signals of the same intensity. Given this non-intuitive polarization-dependence, it is not obvious how the photocurrent will vary in cross-correlation measurements, where there are two distinct input polarization states.

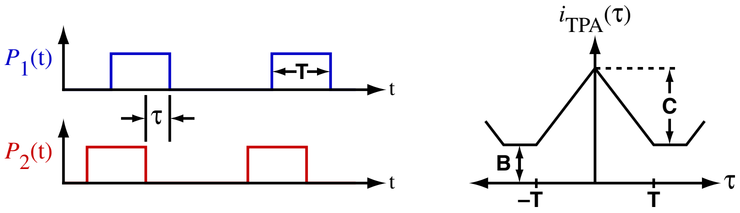

Fig. 1. Example of cross-correlation measurement. The averaged photocurrent is comprised of a background level B and a cross-correlation signal of height C, both of which depend on the input polarization states.

In cross-correlations, the averaged photocurrent $i_{\mathrm{TPA}}(\tau)$ consists of a background level B that is present even when the optical signals do not overlap, along with a cross-correlation signal of magnitude C, as shown above. Both levels depend on the polarization states of the input signals. If the two signals have the same shape, power and perfect extinction ratio, Eq. 1 predicts that B and C are:

$$B = \eta \left[\frac{3}{4} - \frac{1}{8}(S_3^2 + S_3'^2) \right] \tag{2}$$

$$C = \eta \left[1 + \frac{1}{2}(S_1 S_1' + S_2 S_2') \right] \quad , \tag{3}$$

where $\mathbf{S} = (S_1, S_2, S_3)$ and $\mathbf{S}' = (S_1', S_2', S_3')$ represent the normalized Stokes vectors of the incident beams and the constant η depends on the two-photon absorption coefficient, focused spotsize and detector geometry.

Provided it does not change rapidly, the background level B can be automatically removed by filtering [4], chopping [5], dithering, differential detection, or post-detection signal processing [6]. In addition to changes in the background, Eq. 3 predicts that the correlation magnitude C can vary from $\frac{1}{2}\eta$ to $\frac{3}{2}\eta$, depending on the relative polarization states.

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[1] In some semiconductors, there can be polarization dependence and anisotropy depending on the relative orientation of the crystallographic axes and beam direction [3], but we have verified experimentally that Eq. 1 accurately describes the polarization dependence of TPA for a variety of detectors including the silicon APD's described here.

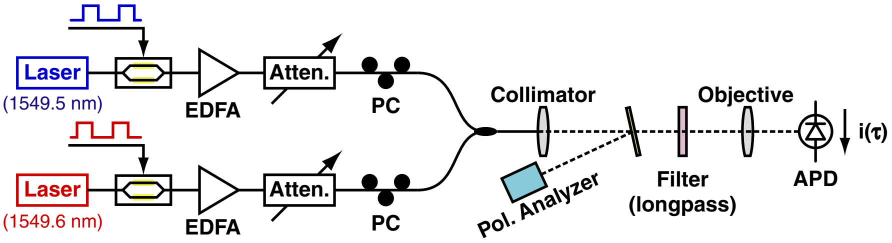

Fig. 2. Experimental setup used to investigate polarization sensitivity in cross-correlation measurements based on two-photon absorption. Each arm produces a train of 300-ns rectangular pulses with a peak power of 8 mW at the detector and a repetition rate of 1 MHz. The cross-correlation is measured with a silicon APD (EG&G C30902E).

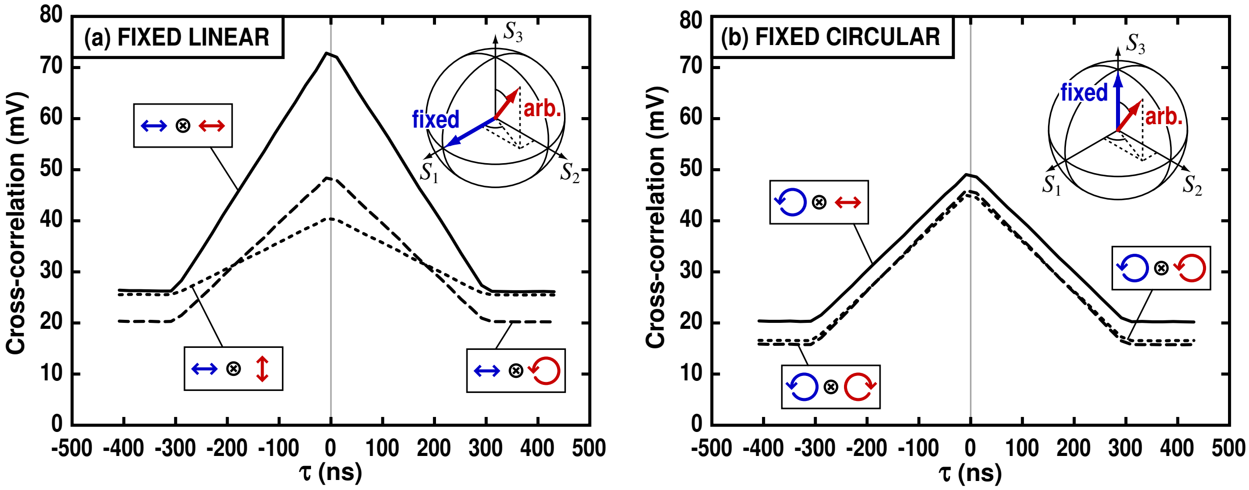

Fig. 3. Measured cross-correlation functions (a) when the fixed input polarization state is linear and (b) when the the fixed polarization state is circular.

In almost all applications, one of the optical signals is generated locally and can therefore have a prescribed polarization. One observes from Eq. 3 that if one of the polarization states is circular (i.e., $S_1 = S_2 = 0$), the cross-correlation term C will be independent of the other state $\mathbf{S}'$. Fig. 2 shows the experiment we used to verify this principle.

As shown in Fig. 3a, when one of the signals has a fixed ***linear*** polarization, the cross-correlation magnitude C varies by a factor of about $3\times$, with the largest correlation occurring for co-polarized linear states and the smallest correlation occurring for orthogonally-polarized linear states. Fig 3b shows that when one of the signals instead has a fixed ***circular*** polarization, the cross-correlation signal is invariant to the second polarization state, and the background level changes by only 25%. These results agree with the simple theory presented above.

In summary, we present a simple theory that accurately predicts the polarization dependence of two-photon absorption in cross-correlation measurements, and we confirm experimentally that by choosing one of the polarization states to be circular, the cross-correlation signal is independent of the second polarization state.

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