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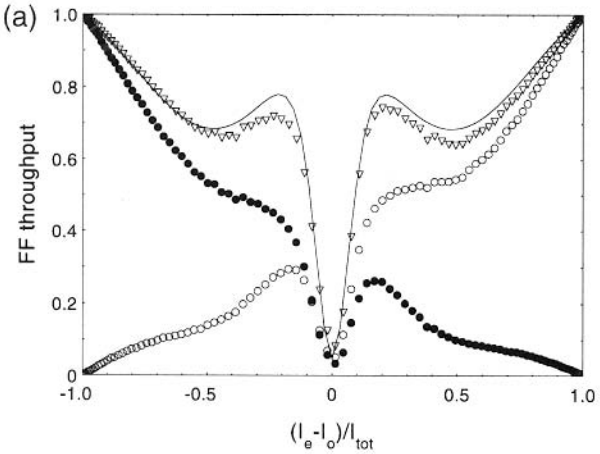
Second Harmonic Generation: Toward an All-Optical Transistor

Z. Wang, D. J. Hagan, and E. W. Van Stryland, CREOL, Univ. of Central Florida, Orlando, Fla. and Gaetano Assanto, Terza University of Rome, Rome, Italy

One of the goals in the development of all-optical alternatives to electronic processing has been development of an optical equivalent to the semiconductor transistor. Different schemes have been suggested for all-optical (AO) modulators and transistors, most of them based on third-order nonlinearities. More recently, after the experiments by DeSalvo *et al.*, attention has been paid to the cascading of second-order nonlinearities.[1] The possibility of using cascaded quadratic effects to exploit the coherent nature of parametric interactions[2] has spurred interest toward analog AO processes in second-order material systems, first among them the transistor. Recently, various schemes for AO transistor action have been discussed and, in part, demonstrated in the framework of nonlinear cascading through second harmonic generation (SHG).[3, 4] They, however, rely either on a specific structure of the nonlinear susceptibility tensor[4] or on the use of a coherent seed at the SH frequency.[3] A novel approach for all-optical transistor action involves SHG in the case of Type II phase-matching, *i.e.*, through the interaction of two orthogonally polarized waves at the fundamental frequency (FF) to generate a SH wave.[5] In such a case, in fact, a standard crystal allowing Type II phase-matching can be used, and both input and output signals have the same optical frequency. Moreover, the two FF waves at the input, namely pump and signal, need not be coherent to one another.[5]

We have demonstrated the feasibility of an AO transistor in a 2 mm long potassium titanyl phosphate (KTP) crystal, using 25 psec (FWHM) pulses from a Q-switch mode-locked Nd:YAG laser operating at 1.064 μm.[6] Pump and signal inputs were the two orthogonal polarization components of a FF field oriented to nearly phase-match Type II SHG. When the two input amplitudes are not balanced, *i.e.*, the polarization input angle is not exactly 45°, the SHG process is sharply controlled by their relative weights, regardless of their mutual phase relationship, leading to efficient AO modulation in either polarization component and in the total FF transmission. Figure 1a shows experimental data and the theoretical simulations demonstrating such transistor action versus the normalized input imbalance between ordinary and extraordinary components. Noticeably, a modulation contrast of 10:1 is achieved in the total throughput T with a variation of 15% in the relative strength $(I_e\text{-}I_o)/I_{tot}$, *i.e.*, rotation $\Delta\phi \cong 4.3°$ of the linearly polarized input FF field, and a small-signal amplification $\gamma = \Delta T/(I_e\text{-}I_o)$ of 7.9dB. Similar results with reduced variations and smaller rotations are obtained for larger input intensity, with $\Delta\phi \cong 1°$ and $\gamma \cong 14$ dB for $I_{tot} = 32$ GW/cm^2.[6]

The operation of this AO transistor, as mentioned



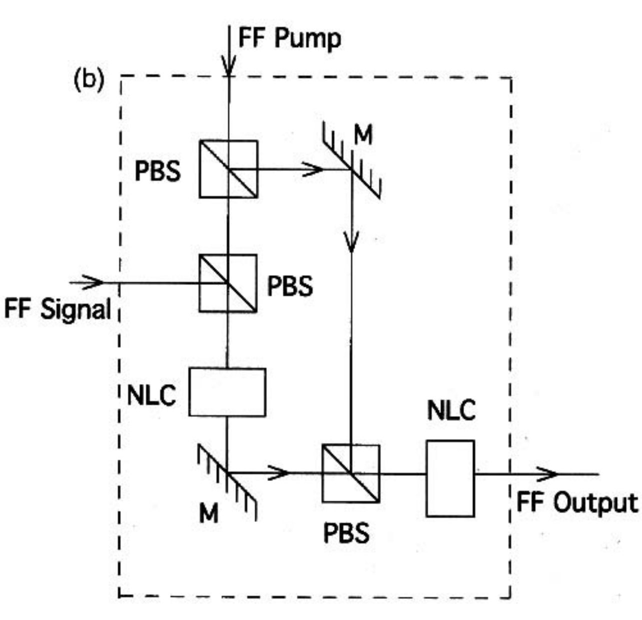


Figure 1. (a) Throughput modulation versus intensity imbalance in the two input components $I_e\text{-}I_o/I_{tot}$, for $I_{tot}=8.5$ GW/cm^2. Empty and filled circles are the experimental data for each ("e" and "o") polarization output, the triangles are the total throughput, and the solid line is the numerical simulation. (b) All-optical transistor configuration using two nonlinear crystals with Type II phase-matching. M=mirror, PBS=polarizing beam splitter, NLC=nonlinear crystal.

above, does not rely on a specific relative phase between inputs. To take full advantage of this characteristic, however, a small signal must be coherently imposed onto a large optical bias to make the two cross-polarized inputs of comparable intensity. Figure 1b shows the two crystal arrangement which we are currently testing to demonstrate small-signal amplification with incoherent inputs. A weak incoherent signal input is transferred onto a large bias at FF in the first crystal by generating a small amount of SH, and the second crystal is the AO-modulator operating with slightly unbalanced inputs.

Acknowledgements
This work was supported by NSF (ECS#9320308) in CREOL and by the Italian MURST (40% -"Photonic Technologies") in Rome. A NATO collaborative grant (#CRG931142) is also gratefully acknowledged.

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OPTICAL ENGINEERING

Depth of Focus Enhancement and Twisted Beams Using Radial Harmonic Pupil Filters

Joseph Rosen, Boaz Salik, and Amnon Yariv,
California Institute of Technology, Pasadena, Calif.

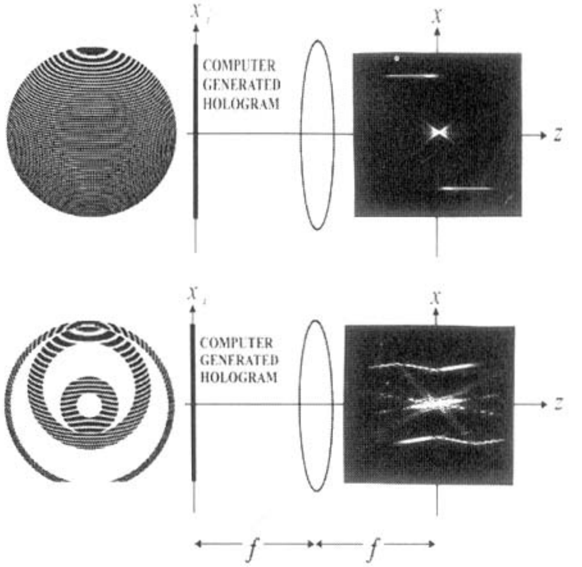

Figure 1. Computer-generated hologram of the radial harmonic function (upper left), and for creating a snake beam (lower left). The intensity distributions around the front focus are shown at right. The sword beams (upper right) and snake beams (lower right) are obtained in the ±1 diffraction orders.

It is well known that when a plane wave crosses a simple spherical lens, it is focused at the lens's front focus. When one measures the intensity profile along the optical axis, one sees a bell-like curve around the focus, *i.e.*, a strong intensity peak in the focal point that falls off rapidly as we move away from it on either side.

The goal we address is avoiding this typical behavior of the light. We have proposed[1-3] placing filters in the light's path so that a sword beam is obtained around the front focus. A sword beam is a beam that maintains an almost constant intensity along the optical axis, for an arbitrary interval, and whose lateral width at any cross section is similar to that of the ordinary beam mentioned above.

A well-known method to achieve this goal is to place an aperture with the form of a narrow ring at the rear focal plane of the lens.[4] The main problem with such an aperture is that only a small portion of the light passes through the ring and becomes useful in the front focus.

We propose placing a different filter in the rear focal plane of the lens. Our calculations show that a Fourier computer-generated hologram of a radial harmonic function on the order of four or more, also yields a sword beam around the front focal plane.[5] The properties of this sword beam can be controlled by the various parameters of the filter. If we choose a radial harmonic function of order four *i.e.*, $g(r) = \exp[j2\pi(r/b)^4]$, no light is absorbed at all in the system. That is because this is a phase-only filter. This is one big advantage of our method over the ring aperture. In addition, we have found that by various, well-defined changes of the original radial harmonic function, we can shift the sword in any direction in the entire space, and even tilt it by some angle (up to 20° from the optical axis in any direction).

Using the radial harmonic functions and the Fourier hologram's properties, we have created an arbitrary longitudinal focal line.[6] We proposed to compose several holographic elements, each of which creates a small