10:30am-11:00am (Invited)
ThH1

Applications of Cascading Nonlinear Optics to All-Optical Devices

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Cascading is the process by which second order nonlinearities, when used near phase-matching for parametric mixing processes such as second harmonic generation (SHG), can be used to mimic some effects normally associated with third order nonlinearities, more specifically with an intensity-dependent refractive index. The fundamental beam on transmission through a $\chi^{(2)}$-active medium has the form:

$$E_0(\omega) = \frac{1}{2}|a_0(\omega,z)|\sqrt{\frac{2}{cn\epsilon_0}}\exp\left[i(\omega t - kz - \phi^{NL}(z))\right] + c.c.$$

away from the phase-matching condition there is a nonlinear phase shift $\phi^{NL}(z)$ induced whose magnitude and sign depends on the detuning from phase-matching. (There are also interesting effects associated with the amplitudes of the fundamental and second harmonic, including the formation of solitary waves - these will not be discussed here.) It is well-known that nonlinear phase shifts in general are needed for all-optical switching devices and in this paper we will describe the application of such cascaded phase shifts to a fully integrated nonlinear directional coupler and Mach-Zehnder interferometer.[1-4]

The devices utilized Type I phase matching in a 50mm long Titanium indiffused symmetrical channel waveguide with propagation along the X-axis on a Y-cut $LiNbO_3$ crystal. Temperature tuning is required at 1320 nm to implement SHG and the experiments were conducted in an oven around 340°C. The key to the successful implementation of devices in these waveguides was the temperature distribution in the oven (uniform in the middle and decreasing towards the input and output windows) which allowed large phase shifts (>1.5π) to be obtained with minimal net losses in the fundamental throughput due to SHG (~10%).[2]

Both a nonlinear directional coupler (NLDC) and Mach-Zehnder interferometer (NMZI) were made on a $LiNbO_3$ substrate.[3,4] The modelling of the devices was complicated by the presence of four coupled fields and the spatial distribution of the wavevector mismatch was optimized so that SHG is minimized at both outputs simultaneously. The final designs were fabricated and tested with a Nd:YAG laser operating with 90psec pulses. The results are shown in Figs. 1 and 2. For the MZI it is clear that as the input power is increased, the throughput is modulated between >80% to less than 20% of the input. Similarly, for the NLDC, the switching from the CROSS to the BAR states with increasing power is clear.

Fig. 1: Measured transmittance of a $LiNbO_3$ integrated Mach Zehnder interferometer as a function of the peak input power with initial phase difference of $\approx\pi$ between the two arms (solid curves, experiment; dotted curves, theory).

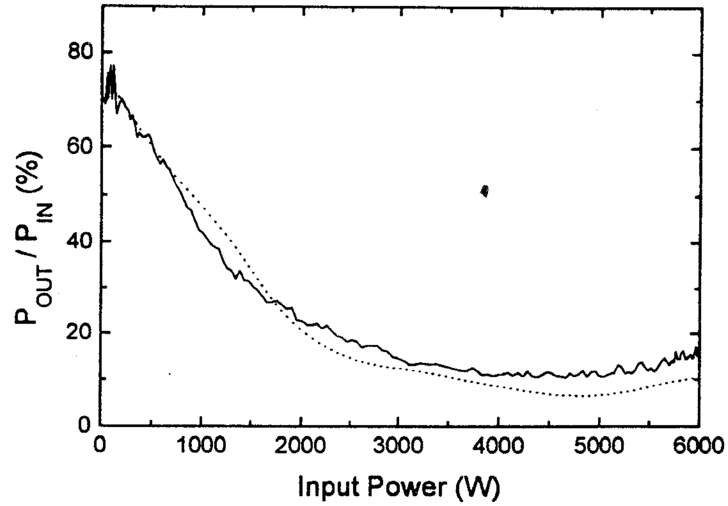
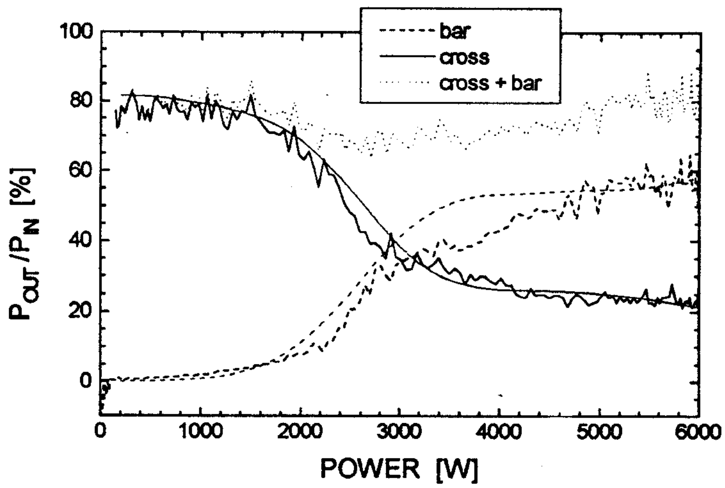


Fig. 2: Power-dependence of a NLDC fundamental output for a crystal temperature of 343 °C. Smooth curves are theory.



The switching powers in these two applications are in the KW range. These waveguides have large modal areas ($A_{eff} \approx 75\ \mu m^2$) and utilize small second order nonlinearities (5 pm/V). There are materials now available with $d^{(2)}$s of 600 pm/V, and in which waveguide containment can be optimized. The switching power varies as $|\chi^{(2)}|^2 A_{eff}$ and we expect that milliwatt switching powers will ultimately be possible.

References:

[1] G.I. Stegeman, SPIE Proceedings on Nonlinear Optical Properties of Advanced Materials, **1852**, 7 (1993).

[2] R. Schiek, M.L. Sundheimer, D.Y. Kim, Y. Baek, G.I. Stegeman, H. Suche and W. Sohler, Opt. Lett., **19**, 1949 (1994).

[3] R. Schiek, Y. Baek, G. Krijnen, G.I. Stegeman, I. Baumann and W. Sohler, Opt. Lett., in press

[4] Y. Baek, R. Schiek, G. Krijnen, G.I. Stegeman, I. Baumann and W. Sohler, Appl. Phys. Lett., **68**, 2055 (1996)