The all-optical processor has been a dream for over two decades now, with the effective and practical implementation of such proving elusive. This dream appears to have fallen by the wayside with the blindly impressive progress of late in silicon-based computing, but almost ironically it is this very advancement that is bringing forward a new application for all-optical logic information routing. Optical (fiber optic) communication is very successfully solving the world’s need for information transfer, but even still the information must be constantly received electronically and resent in order to steer it to its destination. This process is slow in comparison to the basic information propagation speed in optical fibers, and is quickly becoming the weak point in the global information network. Its most obvious replacement is all-optical logic switching.

The main problem with optical logic is that the operation of a logic gate that works on two inputs is essentially a nonlinear process, whereas electro-magnetic waves in most media are solutions to the linear waveequations; in most dielectrics light does not interact with itself. However, in recent years there has been considerable advancement in the theory and manufacture of nonlinear optical media, which now opens a new and exciting range of possibilities for implementing all optical logic circuits.

One such possibility is the implementation of an all-optical AND gate as proposed by Drummond et al. In this method the two optical inputs are coiled non-collinearly in a dispersive parametric planar waveguide, as illustrated in Fig. 1.

Consider firstly type II interaction in which the pulses have orthogonal polarizations, if only one pulse at a time is injected into the waveguide then it simply disperses. Whereas if two pulses arrive simultaneously then when they collide a phase-matched second harmonic is generated that traps the original two fundamentals, forming a 2+1D spatiotemporal soliton, which propagates stably towards the logic true output. Finally, it is also apparent that when no pulse is present on either input then no output will be generated. In this fashion AND gate logic operation is achieved. For such 2+1D solitons to form the basic requirements are anomalous dispersion and (nearly) matched group velocities at the fundamental and second harmonic frequencies. As of this year, 2+1D solitons in parametric media have been experimentally observed.

One of the key factors that determines the feasibility of the proposed implementation is its sensitivity to perturbations in the critical input parameters. In the case of type II interaction two of the more critical input parameters are: a) time separating the arrivals of the individual pulses and b) their initial transverse separation when they enter the χ(2) section of the planar waveguide. This has been investigated by numerical simulation and the results of one instance displayed in Fig. 2. The values used for nonlinearity, dispersion, and fundamental wavelength were χ(2) = 10 pm/√W, β2 = 25 psec/m, and λ = 1.5 μm respectively, and for the switching to take place within an available length of χ(2) media of say 50 mm, we find that the incident pulses are of transverse width 140 μm, duration 45 fs, and energy 8 pJ. Note that negative transverse separation corresponds to the point of intersection of the pulses being inside the χ(2) medium, whereas positive separation corresponds to the pulses having already crossed before reaching the interface.

Here the steep "cliffs" in the total transmitted energy indicate that the switch has a highly digital response in terms of these two parameters, thus making it very well suited to logic operation. In fact it is apparent that the actual time discrimination of the gate is of the order a few femtoseconds for the parameters used here.

Investigations into the performance of a switch using type I (degenerate) interaction have also been made with results that contrast significantly to those of the type II interaction case. In particular we find that type I switching is extremely phase sensitive.


Digital response in an all optical AND gate using parametric (χ(2)) solitons

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