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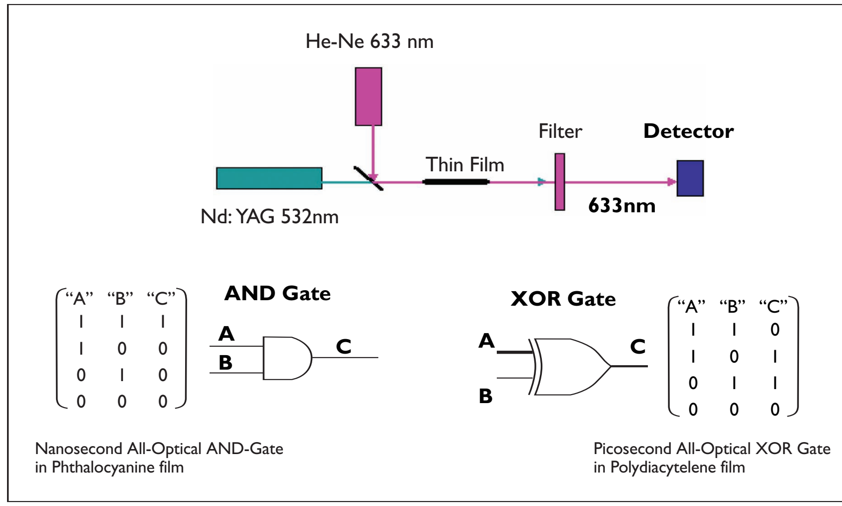
OPTICAL COMPUTING: NEED AND CHALLENGE

Focusing on the reality and promise of optical computing.

An optical computer is a device that uses photons, thin films, crystals, and optical fibers to perform digital computations. Since the advent of lasers in 1960, researchers have thought of using lasers and fibers for computing. Optical computation is the most feasible technology that can replace electronics, and promises impressive speeds that can enhance processing power and data rate transmission. The recent revival of optical computing technology is due to an ever-increasing need for computational speed and the recent developments in building super "tiny and fast" transistor-like all-optical switches.

Why Optics for Computing?

Lasers, fibers, and optical components have already proven their reliability and high levels of performance in many applications such as CD-ROM drives, laser printers, photocopiers and scanners, Storage Area Networks (SANs), optical switches, all-optical data networks, holographic storage devices, and biometric devices at airports to track weapons and drugs. At the same time, the promise of optical computing comes from the many advantages that optical interconnections and optical integrated circuits have over their electronic counterparts. Optical computing is immune to electromagnetic interference and free from electrical



A schematic of an all-optical AND and XOR logic gates, which were demonstrated in phthalocyanine and polydiacytelene thin films in the nanosecond and picosecond regimes respectively.

short circuits. Photons of different colors can travel together in the same fiber or cross each other in free space without interference or cross-talk. Photons have low-loss transmission and provide large bandwidth, offering multiplexing capacity for communicating several channels in parallel without interference. Optical materials are compact, lightweight, inexpensive to manufacture, more facile with stored information than magnetic materials, and possess superior storage density and accessibility compared to magnetic materials. Progress in holographic storage devices can enable storage of the entire U.S. Library of Congress onto a sugar-cube-size hologram. Furthermore, optical parallel data processing is easier and less expensive than electronic. In addition, optical computing systems offer computational speeds more than 10^7 times faster than the currently fastest electronic systems. This means a computation that takes a conventional computer more than 11 years to solve would take an optical computer less than one hour.

What Does "All-Optical" Mean?

An all-optical system means an optical signal in a logic gate controls another optical signal by switching it on/off without external electronic components. Logic gates are the building blocks of any digital system. The light beam is "on" when the device transmits light and is "off" when it blocks the light. Photonic switches can perform in the picosecond (10^{-12}s) and femtosecond (10^{-15}s) range as has been demonstrated in polydiacetylene [9].

An all-optical AND logic gate in the nanosecond (ns) (10^{-9}s) range was demonstrated in our laboratory (see the figure here), where the ns Nd:YAG at 532nm modulated a continuous-wave helium-neon (cw He-Ne) laser at 632.8 nm in a metal-free phthalocyanine thin film. The AND logic gate was attributed to the saturation of absorption mechanism in the film. Another all-optical XOR logic gate in the picosecond regime was also demonstrated [1] in our laboratory using a poly-

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diacetylene film, a picosecond Nd:YAG laser at 532nm, and a cw He-Ne laser at 633nm. The switching in the material was attributed, in this case, to excited state absorption. Tens of these logic gates with different physical and optical properties have been demonstrated in different materials and with different speeds [2, 3, 6, 8, 10, 11].

Optical Computing Systems: Why Not and How Long?

Since the building blocks, such as all-optical logic gates, optical switches, optical memory, and optical interconnections are all available, why then don't we have an optical computing system? There are several factors impeding the technology, the most important of which are: cascadability, material development, and funding. Cascadability to integrate a large number of all-optical gates is a highly complex problem and a major obstacle in the way of building a complete optical computing system. Binary half adders data processors, which combine several optical logic gates, are the basic building blocks of binary operations. Several of them have been successfully demonstrated [4, 7]. An all-optical half adder at a rate of 10Gbps was recently demonstrated by Kim et al. [5]. Nonlinear optical mechanisms play important roles in ultra-fast, all-optical logic gates and optical switches. Most of the nonlinear mechanisms in these switches require pumping high optical power into the system for these devices to function. However, the high optical power in the system has the disadvantage of generating undesirable signals such as stimulated Brillouin scattering (SBS) and self-phase modulations (SPM), which might affect the system's reliability. Material scientists and chemists, therefore, have the challenging problem of finding materials with adequate response at low power and at the same time demonstrate reliability, speed, and optical efficiency.

Furthermore, development of an optical computer is an interdisciplinary enterprise requiring coordination and funding of optical engineers, material scientists, chemists, physicists, computer architects, and representatives of other disciplines. Government funding incentives, to fill a gap created by industry's return-on-investment requirements, can encourage formation of such teams and expedite development of optical computer systems. It is projected that the development of a bulky prototype optical computer, capable of duplicating the performance of a conventional desktop, could occur within the next 10–15 years. With the current level of progress in the area of optical computing research, it may easily take up to 15–20 years before optical computers commonly appear on our desktops. C

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