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Integrated Optical Maze

Kansas City Division

E. V. Roos and
J. L. Hendrix

KCP-613-5384

Published June 1994

Topical Report
E. V. Roos, Project Leader

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INTEGRATED OPTICAL MAZE

E. V. Roos and
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Topical Report
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Technical Communications
Kansas City Division

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Abstract

Improvements to Nuclear Weapons Surety through the development of new detonation control techniques incorporating electro-optic technology are reviewed and proposed in this report. The results of the Kansas City Division's (KCD's) literature and vendor search, potential system architecture synthesis, and device test results are the basis of this report. This study has revealed several potential reconfigureable optical interconnect architectures that meet Los Alamos National Laboratory's preliminary performance specifications. Several planer and global architectures have the potential for meeting the Department of Energy's applications. Preliminary conclusions on the proposed architectures are discussed. The planer approach of monolithic GaAs amplifier switch arrays is the leading candidate because it meets most of the specifications now. $LiNbO_3$ and $LiTaO_3$ planer tree switch arrays are the second choice because they meet all the specifications except for laser power transmission. Although not a top choice, acousto-optical free space switch arrays have been considered and meet most of the specifications. Symmetric-Self Electro-Optic Effect Devices (S-SEED) free space switch arrays are being considered and have excellent potential for smart reconfigureable optical interconnects in the future.

Summary

Electro-optical devices that can improve the surety of our weapons stockpile are the focus of this project. The current phase of the project focused on the identification of candidate approaches and technologies that can be used in conjunction with a thrust by Los Alamos National Laboratory to improve explosive systems safety. The Kansas City Division (KCD) has been requested to assist Los Alamos in assessing the feasibility of developing electro-optical assemblies that satisfy the surety needs of the weapons complex. Several potential optical interconnection architectures have been identified which address the requirements of output power of $\geq$250 mW, pulse width of 10 ms, optical wavelength of 800 to 1550 nm, and number of gates of >4. In addition, several planer and global architectures have excellent potential for other DOE applications.

The result of the last six months' evaluations shows there are two potential planer architectures that meet the first stage of the stated performance objectives. Planer switch arrays which are based upon $LiNbO_3$ or $LiTaO_3$ directional couplers are being considered as a solution to the Integrated Optical (IO) Maze project. The directional couplers work in a cross or bar state, with an input electrical switching signal. The switch array is a tree structure layout that uses a Ti indiffused or proton exchange directional coupler that is interconnected through single mode

waveguides on a single $LiNbO_3$ or $LiTaO_3$ chip. The monolithic GaAs laser amplifier gate switch array is the most attractive solution to the IO Maze project. This monolithically integrated 1 x N--T-structure--semiconductor laser amplifier switch array incorporates etched-facet turning mirrors with T-branches in a GaAs active waveguide structure. The switch is small and will provide the potential for electrically switching on or off the saturable gain/saturable loss waveguides. The saturable gain/saturable loss waveguide structure can provide +3 dB of gain or >-20 dB of loss per logic gate.

Preliminary results on the evaluation of global optical interconnects are incomplete at present, and there are no clear architectures that meet the stated performance objectives. The results of the evaluation of acousto-optical spatial light modulator (AO-SLM) and symmetric-self electro-optic effect device (S-SEED) based switching architectures are documented in this report. The acousto-optical architecture is an excellent choice for a backup position, if there is a problem with optical damage in the planer approach. The technology is mature; components are available and will meet the specifications, except the system is large and requires considerable electrical power. S-SEED switch arrays do not meet the specifications but are the most interesting reconfigureable switch arrays. This type of device can perform high-speed optical and electronic logic operations in a massive parallel computer architecture. This architecture allows the data to be input optically or electronically and the data to be clocked, processed, and read-out optically. This family of devices can be used to build intelligence into reconfigureable switch arrays.

KCD recommends that further work be performed to fully determine the potential of electro-optical technology in the Nuclear Weapons Complex (NWC). KCD should continue to monitor and interact with the technical community to enable the interests of the weapons complex to be represented and thus capable of taking advantage of the technology breakthroughs. KCD should procure and evaluate GaAs switch arrays because they represent the most logical solution to the current application at present and may provide relatively short-term solutions. This approach, coupled with multimode integrated optic laser amplifiers, promises to provide as much as 600 mW of output from these devices with currently available technology. KCD proposes to complete the evaluation of the $LiNbO_3$ switch arrays and evaluate laser damage thresholds to determine the practical power transmission capabilities. We would also like to expand this work to include $LiTaO_3$ because this material does not suffer from wavelength-dependent optical damage as does $LiNbO_3$. Construction of an S-SEED breadboard is recommended 1) to become more familiar with this technology, 2) to be positioned to take advantage of the rapid technology development in this area, and 3) to guide industrial development for the NWC contractors.

Discussion

Scope and Purpose

Problem Statement

Los Alamos National Laboratory is improving Nuclear Weapons Surety by developing new detonation techniques that incorporate electro-optical technology. Candidate approaches include integrated optic (IO) mazes, acousto-optical (AO) deflectors, and optical switching networks. These technologies are new to weapon system applications. The purpose of this project is to assist Los Alamos in assessing the feasibility of developing electro-optical devices/assemblies that are rugged and manufacturable and that satisfy the needs of the weapons complex.

The Kansas City Division (KCD) has been requested to assist in determining the feasibility of optical switching networks for use as surety devices in weapon detonation systems. Areas to address include integrated optical mazes (cascaded directional couplers), one- and two-dimensional acousto-optical deflector technologies, and other switching networks. While these optical technologies have been successfully applied in commercial applications, the feasibility of producing functional devices that have sufficient robustness to meet stringent and unique weapon requirements is partially unknown. This project will determine the manufacturing feasibility of these advanced electro-optical devices.

Technical Approach

The technical approach will be as follows.

I Conduct a literature and industry search to identify the state-of-the-art for these types of devices.

II Identify vendors and procure commercially available devices.

III Evaluate and characterize procured devices to determine limits, margins, variabilities, technical issues, overall feasibility, and producibility.

IV Test and evaluate prototype optical devices that address the weapons application-specific requirements.

We are currently at stages II and III concurrently, while maintaining an ongoing cognizance over stage I.

Activity

The technical activity of this project is to propose scenarios that will meet the performance specifications outlined by Los Alamos National Laboratory. The specifications are as follows:

- Output power: ≥ 250 mW,
- Pulse width: 10 ms,
- Optical wavelength: 800 to 1550 nm, and
- Number of gates: >4.

Technology Assessment

Architecture

Photonic (electro-optical) switching can be achieved using planer or global optical interconnects which are addressed either optically or electronically. The planer approach uses fiber optics coupled to planer monolithic integrated optical devices in a hybrid electro-optical layout. The global approach uses three-dimensional interconnects through bulk components in an electro-optical layout. Optical interconnects consist of three parts: transmitter, switching device, and receiver. For this report, the receiver will not be considered. The transmitters will be lasers that include laser drivers and control electronics. The switching devices will be the planer or global interconnect switching networks, which are the major focus of this report.

Planer Waveguide Device Switching Networks

Fiber optics and integrated optics are developing technologies that can produce high-performance, high-reliability, and cost-effective solutions. KCD is proposing the use of $LiNbO_3$ (LN), $LiTaO_3$ (LT), or GaAs planer waveguide device switch arrays configured in a tree structure as a possible solution to the current application.

Planer switch arrays based on $LiNbO_3$ or $LiTaO_3$ directional couplers are being considered as a solution to the IO Maze project. The directional couplers, as shown in Figure 1, work in a cross or bar state, where the input from A and B is coupled into output D and E (respectively) for the cross state and coupled into output E and D for the bar state. Input C is the electrical switching signal. Figure 2 is a block diagram of a possible directional coupler layout. The lasers being considered, which will be discussed later in this report, are semiconductor or solid state lasers operating at 1060 or 1320 nm for $LiNbO_3$ and 830 nm for $LiTaO_3$. The directional couplers being considered require that the input laser power be TEM_{OO} and polarized. The polarized single mode laser is pigtailed with a single mode polarization-preserving optical fiber. The pigtailed laser is butt-coupled to the $LiNbO_3$ or $LiTaO_3$ switch array. The switch array is a tree structure layout that uses Ti indiffused or proton exchange to form an index of refraction difference between the bulk material and the waveguide generated by this process. These waveguides can form directional couplers that are interconnected through the single mode waveguides on a single $LiNbO_3$ or $LiTaO_3$ chip. The directional couplers under consideration are polarization-independent or dependent reverse delta beta switch. Figure 2 is an example of 1 x N fan-out tree structure. The architecture and directional couplers are described in references 1, 2, 3, and 4.

GaAs laser amplifier gate switch arrays are the most attractive solution to the IO Maze project. This monolithically integrated 1 x 4 tree structure, semiconductor laser amplifier switch array, is illustrated in Figure 3. This device incorporates etched-facet turning mirrors with T-branches in AlGaAs, or InGaAs, SQW-GRINSCH (Strained Quantum Well Gradient Index Separate Confinement Heterostructure) active waveguide structures in a GaAs substrate. The switch is small and will provide the potential for electrically controlled optical gain and gating functions. In addition, this device will also absorb light when not activated ($\sim$ -20 dB/gate). The

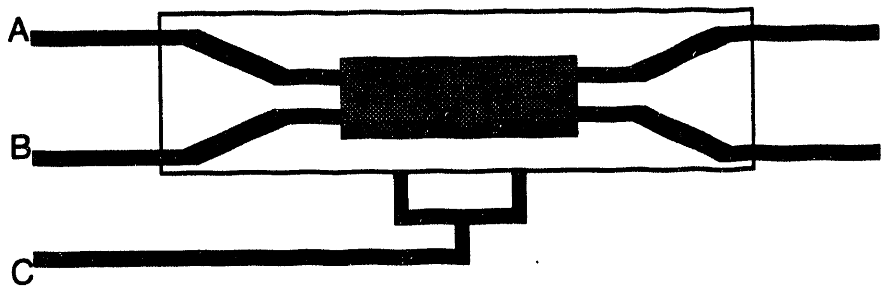

Figure 1. The Directional Coupler Scheme Allows the Logical Operations of AND and OR to Act as the Building Blocks for More Complex Logic Operations. (With C Input ⇔ A and B pass to D and E, respectively. Without C Input ⇔ A and B are exchanged and pass to E and D, respectively.)

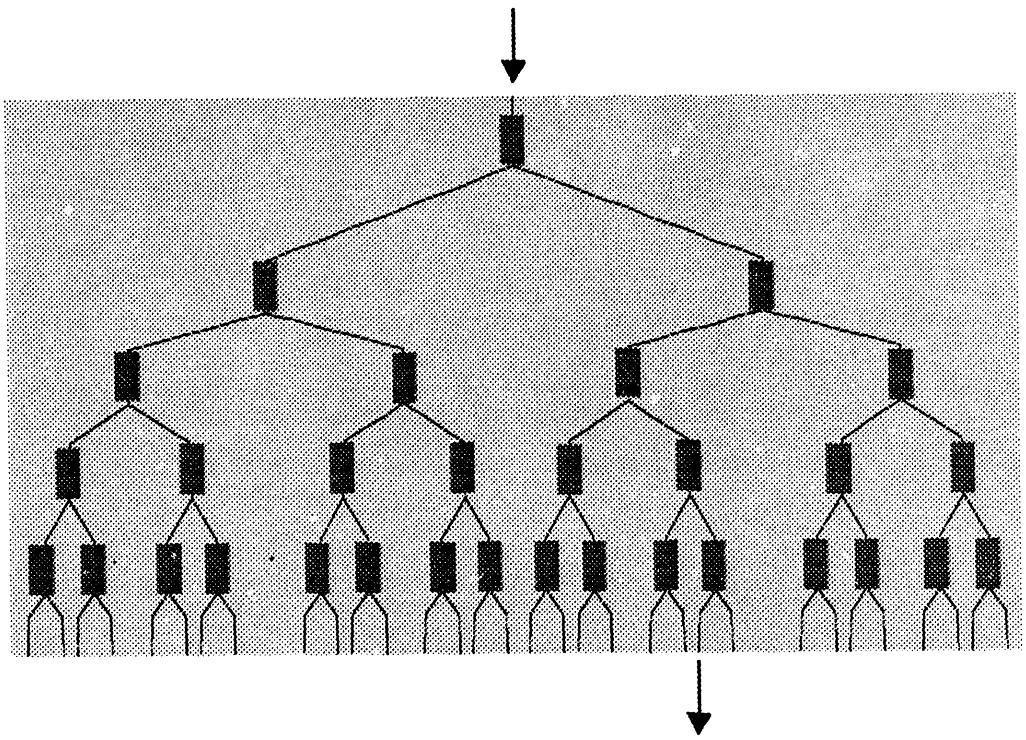

Figure 2. A 1 x N Directional Coupler Tree Structure Illustrates a Potential Topology for Surety Device Switching.

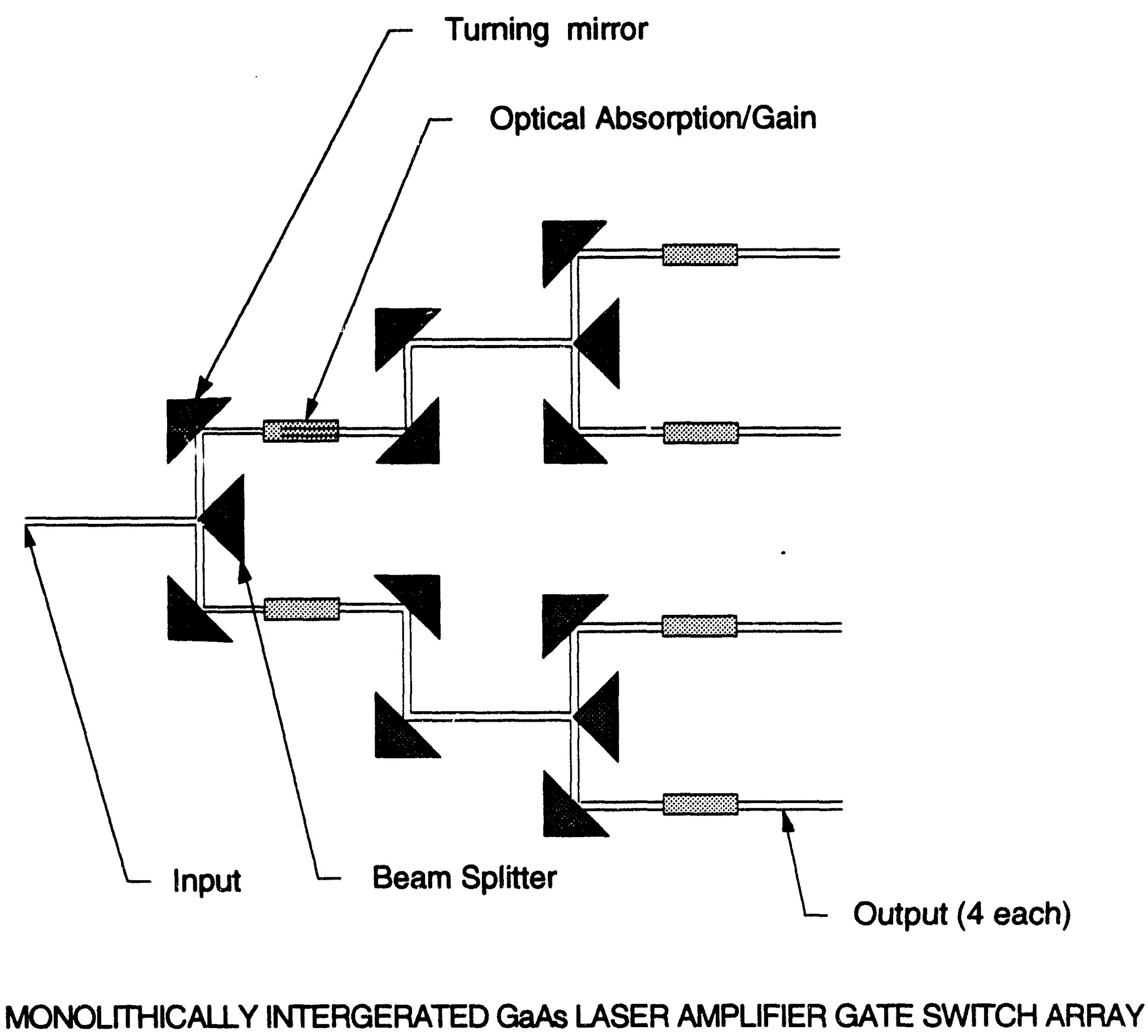

Figure 3. GaAs Switch Arrays Are the Leading Candidate for Photonic Surety Devices Because of Their Power-Handling Capability. (This diagram shows a potential tree structure architecture.)

laser that would operate at 820 or 1550 nm can be integrated in the GaAs substrate, or laser diode may be fiber optically pigtailed to the switch array.

The switch array, as shown in Figure 3, functions in the following manner. The injection laser is turned on, the optical beam within the waveguide is split in two waveguides by the T splitter, and then redirected by the turning mirrors. The two beams pass through active waveguide switch structures. If a positive voltage is applied to the active switch gates, the laser beam will be amplified. On the other hand, if a negative voltage (or ground) is applied to the active switch gate, there will be no output. In other words, a positive voltage performs a saturable gain of greater than 3 dB, and a negative voltage performs a saturable absorption of approximately -20 dB. It is possible to achieve output powers in excess of 250 mW with a fiber-to-fiber insertion loss of less than 1 dB (due to device gain). An extinction ratio of -20 dB can be expected for each amplifier segment that is at ground or negatively biased. The architecture of a monolithically integrated, laser amplifier switch array is described in references 5, 6 and 7.

Several aspects of these devices make them attractive for surety applications. For example, in the commonly quoted nuclear safety scenario of a voltage fault bringing all the electronics into the high state, the devices can be configured so that the laser input pulse is amplified to the point of destroying the waveguide device and thus failing safe. Also the devices can be configured so that some combination of high-low and mid-range voltage is required to allow the device to function properly. The architecture can be layed-out to eliminate direct (in-line) paths, thus eliminating the issue of "what happens if the device goes away." The flexibility of this approach is impressive and can be tailored to the desired application. This approach represents currently available technology that must simply be modified to meet the needs and requirements of WR applications.

Global Switching Networks

Global switching networks offer improved performance over planer switching networks in that they are three-dimensional and are not confined within waveguides. This results in larger numbers of possible interconnects. KCD is proposing the use of optical switches that provide reconfigureable interconnection between "n" lasers and "n" outputs. Figure 4 is a possible layout for an optical crossbar switch, using global interconnects. In this approach, the laser diode arrays, as in Figure 4, are fanned out to illuminate a spatial light modulator (SLM) which consists of N x M transmission or reflection windows. The outputs of the SLM are logical ANDs which are fanned in to form the "n" outputs.

The SLMs under consideration are acousto-optical (AO) devices, ferro-electrical liquid crystal devices, and symmetric-self electro-optic devices. (S-SEEDs are "smart" SLMs.) The global interconnect network that uses SLMs would most likely use 850 or 980 nm laser diodes.

Acousto-optical switching networks are widely used in optical signal processors to address threat warning receivers (for fighter aircraft) and electronic intelligence (ELINT) applications. An approach under consideration using an acousto-optical device is outlined in reference 8. The acousto-optical device used in a pulse imaging mode fits nicely into Figure 4. This can be accomplished by a logical AND as described in equations 1 and 2 and Figure 5.

The major advantages to the AO approach are the high efficiency of light interconnections and AO devices' ability to withstand high laser power. AO devices and their application to AO interconnection are described in references 9, 10, 11, and 12.

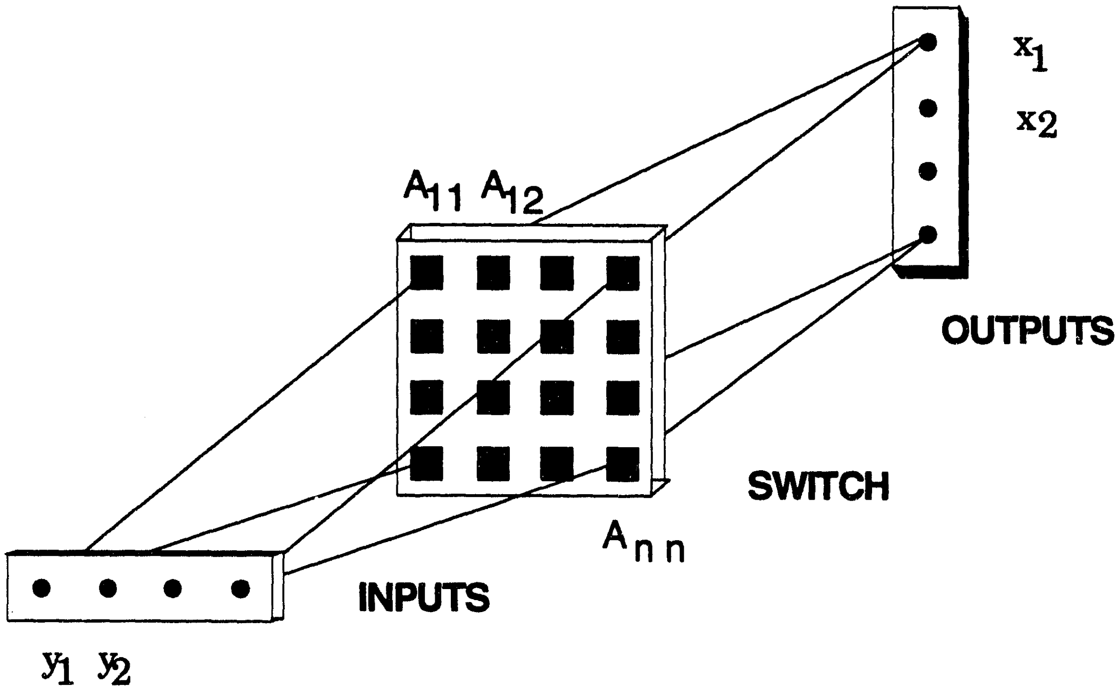

Figure 4. Global Interconnects Are Free Space Devices That Hold a Great Deal of Promise for the Future, in That They Are Capable of Extremely High Interconnect Density.

$$\vec{F} = \vec{A\,X} \qquad (1)$$

$$\begin{bmatrix} f_1 \\ f_2 \\ \cdot \\ \cdot \\ f_{n-1} \\ f_n \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdot & \cdot & a_{1,n-1} & a_{1,n} \\ a_{21} & a_{22} & \cdot & \cdot & a_{2,n-1} & a_{2,n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ a_{m-1,1} & a_{m-1,2} & \cdot & \cdot & a_{m-1,n-1} & a_{m-1,n} \\ a_{m,1} & a_{m,2} & \cdot & \cdot & a_{m,n-1} & a_{m,n} \end{bmatrix} \bullet \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_{n-1} \\ x_n \end{bmatrix}$$

Output Field Control Mask Data Field

(2)

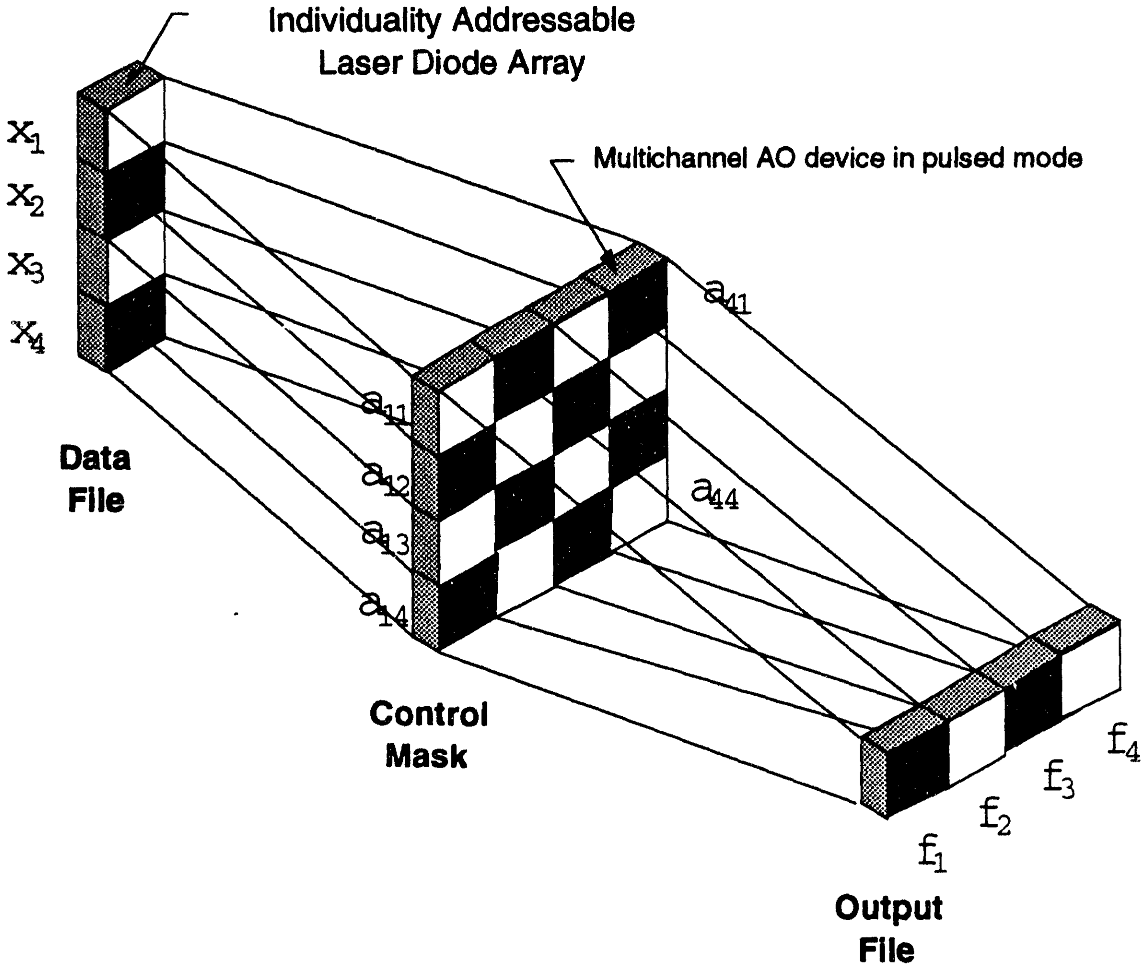

Figure 5. Acousto-Optical Interconnects Are Capable of Matrix Logic Operations That Are the Basis for Optical Computing Architecture.

S-SEED switching networks are an emerging technology offering the potential for optical interconnects based upon optically controlled logic functions. The symmetric-self electro-optical effect device (S-SEED) is a two-dimensional array of active semiconductor devices, connected with beams of light propagating perpendicular to the array. S-SEEDs rely on the change in optical absorption that occurs in response to a change in electric field across a semiconductor quantum well. The electric field can be changed directly to get the device to modulate light in response to the electric field. In S-SEEDs one or more photo detectors produce this change in the electric field. Thus, S-SEEDs have optical input and optical outputs. Optical-to-electrical and electrical-to-optical conversions take place in this device. If S-SEEDs are integrated, they can be among the most efficient devices proposed for optical processing systems.

The S-SEEDs have two p-i-n diodes (see Figure 6), each containing quantum wells in the intrinsic region, connected electrically in series, with one diode behaving as the load for the other (and vice-versa). In operation, two sets of two beams are incident on the device. First, a set of unequal power beams sets the state of the device. With the difference in optical power between the beams, the device can be forced into one of two stable states. The second sets of beams are of equal power. These clock beams are used to read the state of the device.

The S-SEED has the basic functionality of a set-reset latch, although it can do logic functions (NOR, NAND, OR, AND) by using optical beams to reset the state of the device before the application of the input (clock) signal. S-SEEDs are obviously good candidates for memory storage devices as well.

The logic diagram for two S-SEEDs connected in series, which will be defined as a *two-module*, is shown in Figure 7a. This output is routed to two nodes in the next stage of a multistage network (that is, fan-out of two). The simplest optical implementation of a *two-module* is with a

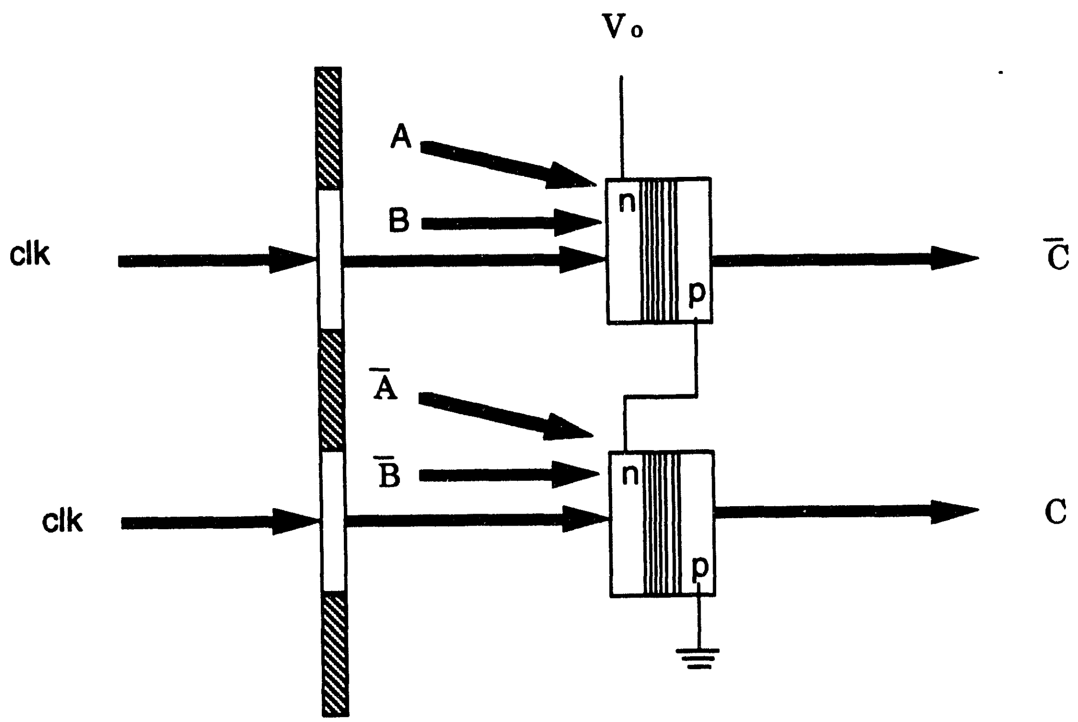

Figure 6. The S-SEED Device Performs the Same Logical Functions That Are Shown in Figure 5. (However, the S-SEED is capable of much higher speed and interconnect density. Currently devices with over 32,000 pairs of S-SEEDs are being made by a supplier. In addition, these devices can be combined in massively parallel and serial combinations to perform extremely complex logic operations.)

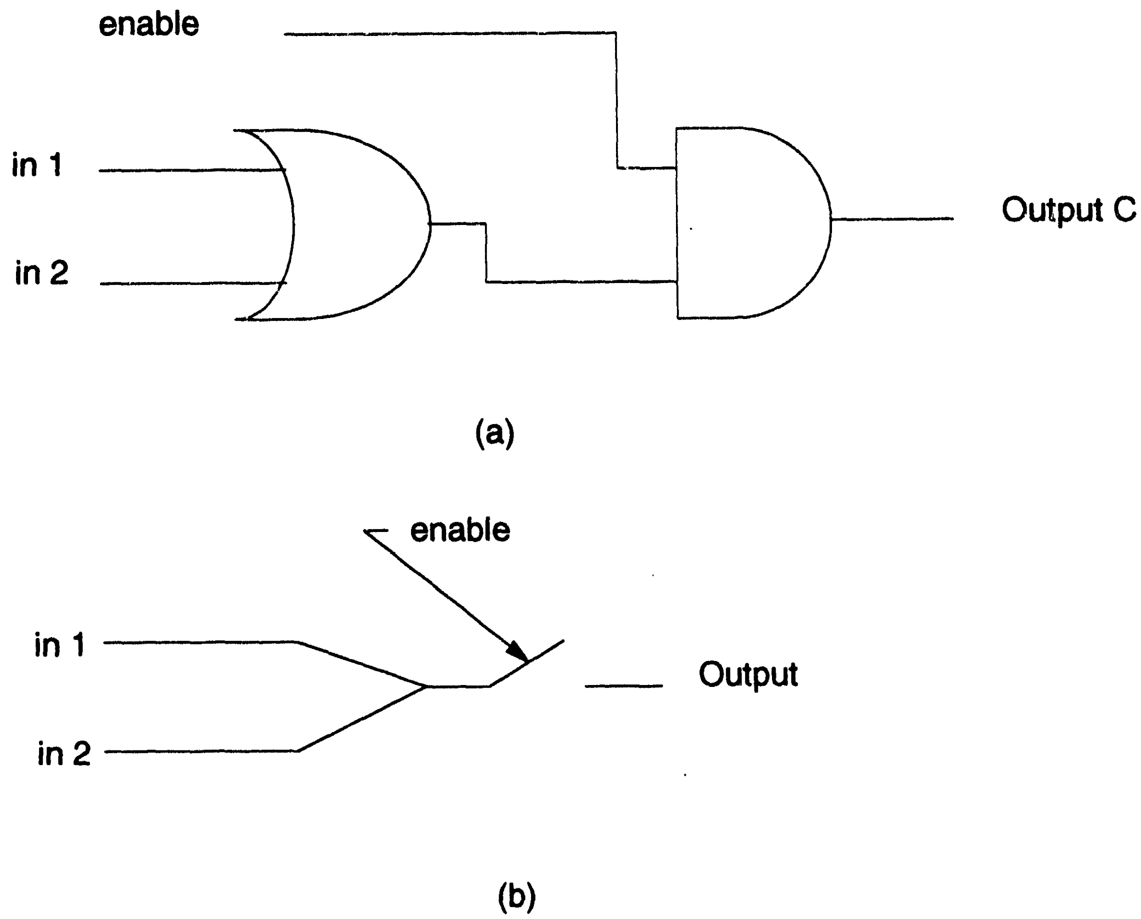

Figure 7. Schematics for Two Modules: (a) an OR/AND Gate and (b) a Tri-State Buffer

single S-SEED, as shown in Figure 6. Schematically, this *two-module* is best represented by Figure 7b. In this module the S-SEED is used as a set-reset latch. Each of the logical inputs of the device is represented by a pair of beams. Therefore, two pairs of input beams are the signal incident on the device, although in a system, one pair will be severely attenuated because of the control of the two modules in the previous stages of the network. Each of the two data inputs is defined to be a logic 1 when $A > \overline{A}$ and $B > \overline{B}$. The clock beams for the S-SEED *two-module* are passed through an SLM. The SLM provides for the control of the *two-module*. The SLM is set to its nontransmitting mode. In this case, there is essentially no clock beam incident on the device and there will be no output beams. To enable the *two-module*, the SLM is set to its highly transmitting mode, then the clock beam reads the state of the device. If the output is defined to be a logic 'one' when $C > \overline{C}$, then the data output will be equal to the single data input that was present. The architecture of the S-SEED switch array is described in references 13, 14, and 15.

Lasers

The performances of semiconductor and solid state lasers have made significant improvements in the past year. AlliedSignal has restricted the evaluation to TEM_{OO} mode semiconductor lasers which lase between 829 and 1550 nm and TEM_{OO} and multimode solid state lasers which lase at 1064 and 1320 nm because of the input and transmission requirements of the identified maze devices. Table 1 outlines the current performance limits of the lasers. In addition, we have evaluated the performance of semiconductor amplifiers which have the potential of high power output.

The solid state lasers evaluated were diode pumped Nd:YAG and Nd:YLF, while the semiconductor lasers were AlGaAs and InGaAs devices. Figure 8 summarizes the wavelength versus laser material for a broad spectrum of laser sources.

Accomplishments

KCD has identified several potential optical interconnection architectures that address the guidance we received from Los Alamos (as presented previously). In addition, several planer and global architectures that have excellent potential for other DOE applications have also been identified. In this section, we will outline the results of KCD's literature search, vendor search, potential system architecture, and device test results. Preliminary conclusions on the proposed architecture will be discussed in this section for

- Monolithic GaAs amplified switch array,
- Monolithic $LiNbO_3/LiTaO_3$ switch array,
- Acousto-optical global switch array, and
- S-SEED global switch array.

Table 1. Most Promising Laser Sources and Their Performance Parameters

Type of Laser	Mfg. Process	Pulsed Power (mW)	Wavelength (nm)	Efficiency (%)
Semiconductor	AlGaAs, Index Guided QW	400	850 ±25	25
Semiconductor	InGaAs, Index Guided QW	1000	1500	25
Semiconductor	InGaAs, Index Guided SQW	1000	900 to 1100	25
Semiconductor	InGaAs, Index Guided SQM	300	980 ±100	25
Nd:YAG	Diode Pumped	2500	1300	10
Nd:YAG	Diode Pumped	5000	1064	10

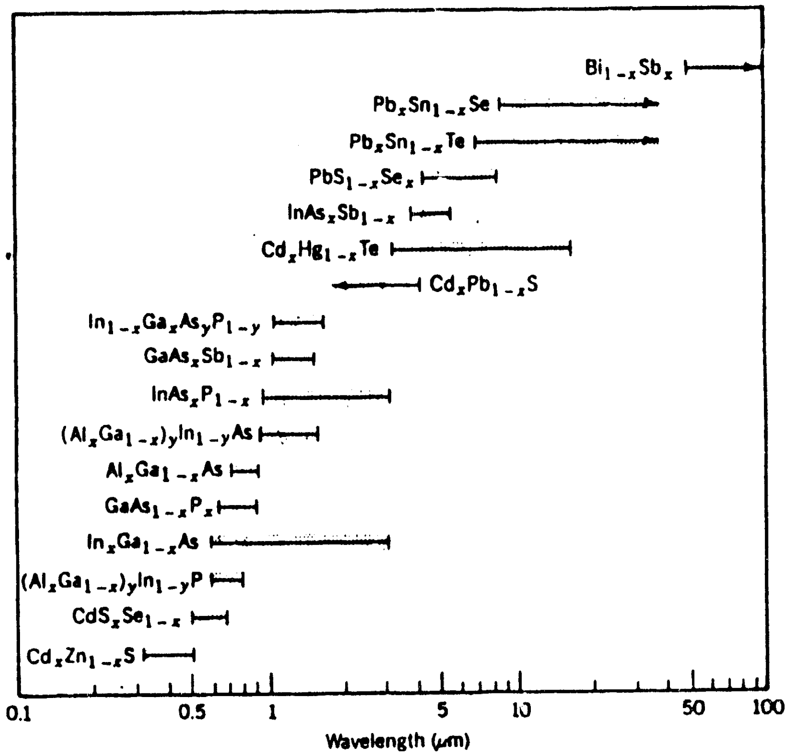

Figure 8. Compound Materials Used for Semiconductor Lasers. (The range of wavelengths for currently available laser diodes reaches from the near ultraviolet to the far infrared. Semiconductor lasers operating at λo > 3 μm usually require cooling below T = 300 K. Some of these materials require optical or electronic beam pumping to lase.)

Planer Waveguide Device Accomplishments

The result of evaluations performed over the last six months shows that there are two potential candidate architectures which meet the first stage of the stated performance objectives. These candidates are $LiNbO_3$- or $LiTaO_3$-based directional coupler waveguide devices and InGaAs or AlGaAs active waveguide switch arrays.

GaAs Active Waveguide Switch Array

GaAs switch arrays are the most attractive solution identified and should meet the WR requirements, as well as the project/application-specific goals. This architecture is attractive due to optical power gain, switching speed, size, total integration similar to an electrical hybrid, manageable power requirements, high device efficiency, and nuclear radiation hardness of GaAs-based semiconductor devices. The disadvantage to this approach is that it is an emerging technology which will require developmental funding, as well as time, to develop the technology and packaging of the device. Depending on the desired architecture and required functions, devices of this type could be manufactured at WR production rates in a matter of a couple of years.

Specifications for this device are as follows.

- Optical power per channel: >600 mW
- Number of switching nodes: >8
- Switching speed: <20 ns
- Space required depends on architecture desired - approximately 1 cubic inch.
- Optical wavelength: 830 or 940 nm

Two laboratories can develop GaAs switch arrays to meet WR requirements. (See the Appendix for a white paper outlining this activity.)

Figure 9 shows a potential architecture for a surety device using GaAs active waveguide switch arrays.

$LiNbO_3$ Directional Coupler

The second most attractive approach is the reverse delta-beta $LiNbO_3$ or $LiTaO_3$ directional coupler arranged in a modified tree structure. This device is constructed on a single $LiNbO_3$ or $LiTaO_3$ substrate. $LiNbO_3$ can be used for optical wavelengths of 1060 to 1550 nm, while $LiTaO_3$ can be used for 850 nm.

The directional coupler architecture is attractive for its 1) low optical attenuation (3 dB loss in and out of the substrate and 0.5 dB per coupler), 2) proven manufacturing processes, 3) high on-to-off ratios, 4) low electrical power requirements, 5) high switching speeds, and 6) reasonable development costs. A disadvantage is that they require development of high-power TEM_{00} mode semiconductor laser diodes which operate at greater than about 1000 nm (1550 nm is a promising choice that industry is pursuing heavily) because of wavelength-dependent optical damage within $LiNbO_3$ waveguides. (The lower the wavelength the greater the probability of damage.)

Preliminary specifications are as follows:

- Output power per channel: ≥250 mW,
- Number of switching nodes: ≥8,
- Switching speed: ≤20 ns,
- Optical wavelength: 1064 to 1550 nm, and
- Size: 20 cubic inches.

A supplier can provide devices which can meet our need.

Figure 10 shows a potential architecture for a surety device using the $LiNbO_3$ switch arrays.

Global Interconnection Accomplishments

Preliminary results of global optical interconnect evaluations are incomplete at present, and there are no clear architectures that meet stated performance objectives. The results of the evaluation of AO-SLM- and S-SEED-based switching architectures are documented in this section.

Acousto-Optical Switch Array

Acousto-optical switch arrays are the most commonly used global optical

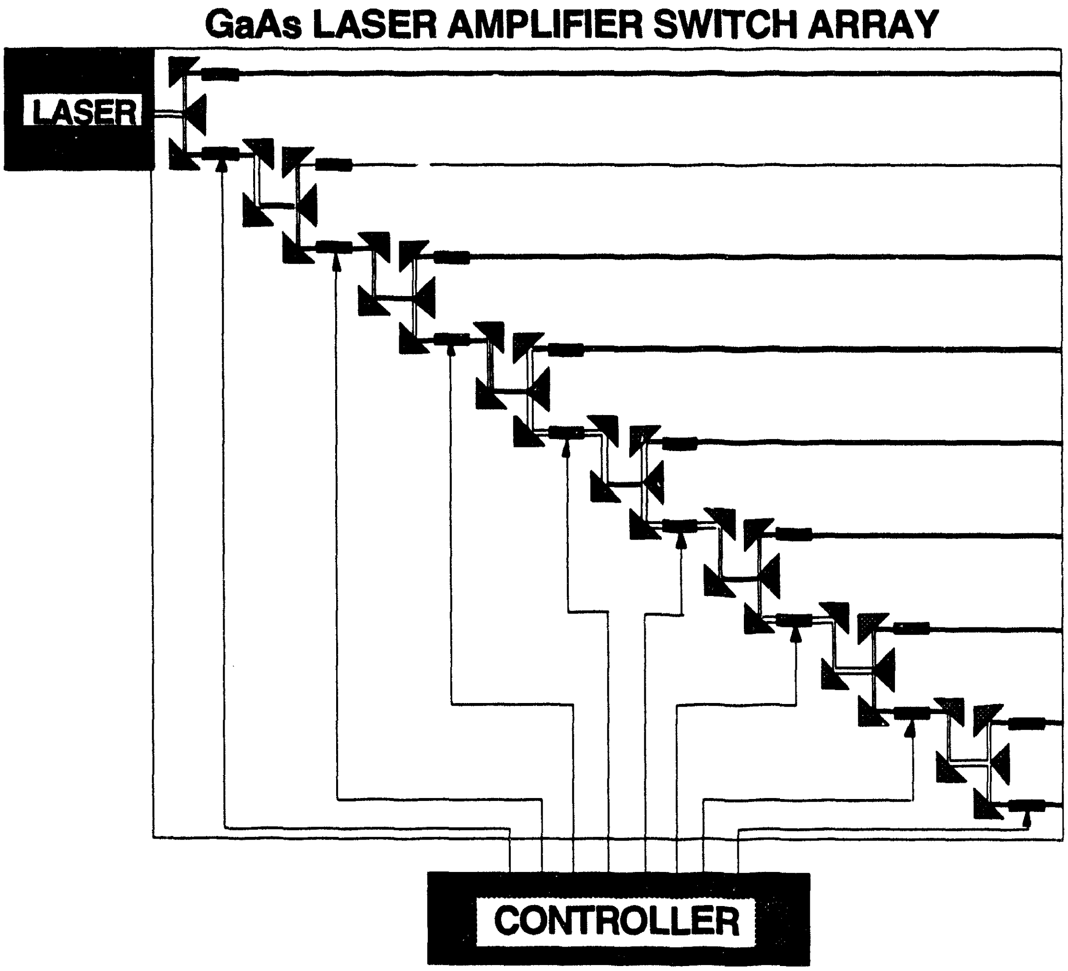

Figure 9. The "Active Wave Guide" Approach Can Be Configured in a Multitude of Architectures. (This technology is very similar to electronic integrated circuits and would be the complexity of a typical hybrid microcircuit. The device could be as simple as a single gate or as complex as a large pruned binary tree.)

interconnection architecture. This architecture is an excellent choice for a backup position, for example, if there is a problem with optical damage in the planer approach. The technology is mature and components are available and will meet the specifications. However, the system is large and requires considerable electrical power. Figure 11 shows an optical layout which uses several AO devices in series and forms the same type of structure as the waveguide tree architecture. The disadvantages of this architecture are large system volume, poor power efficiency, and a challenge to package for the environmental conditions. Figure 12 shows a two-dimensional approach that generates a global interconnect scenario which is

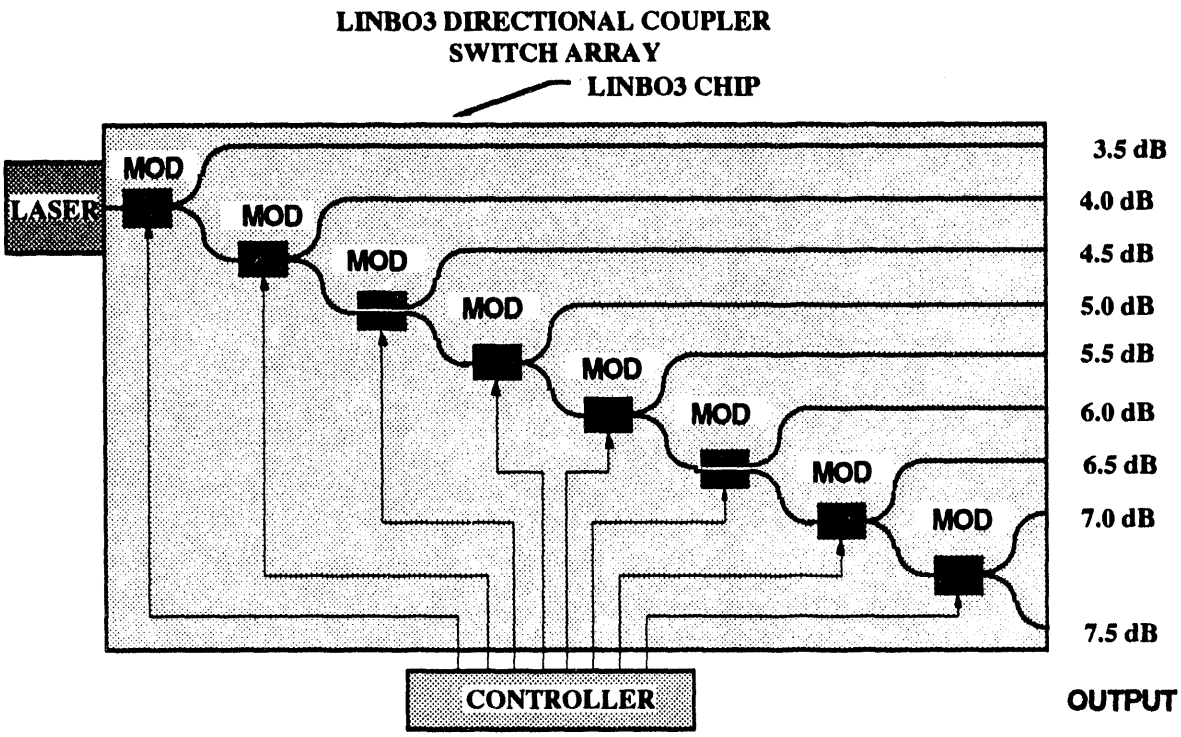

Figure 10. $LiNbO_3$ Switch Arrays Can Be Configured in Many Different Architectures, From the Simple Directional Coupler to Multi-Tiered Binary Trees to Large Crossbar Switches

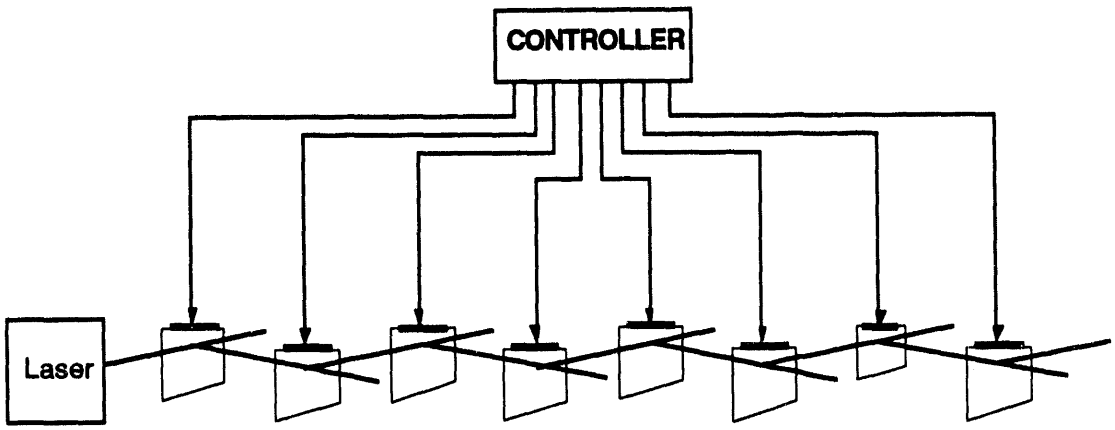

Figure 11. The Serial AO Architecture Layout Would Perform the Multi-Gate Logic Operation of a Safety Device for Nuclear Surety but Requires Large Amounts of RF Power and Is Unacceptably Large.

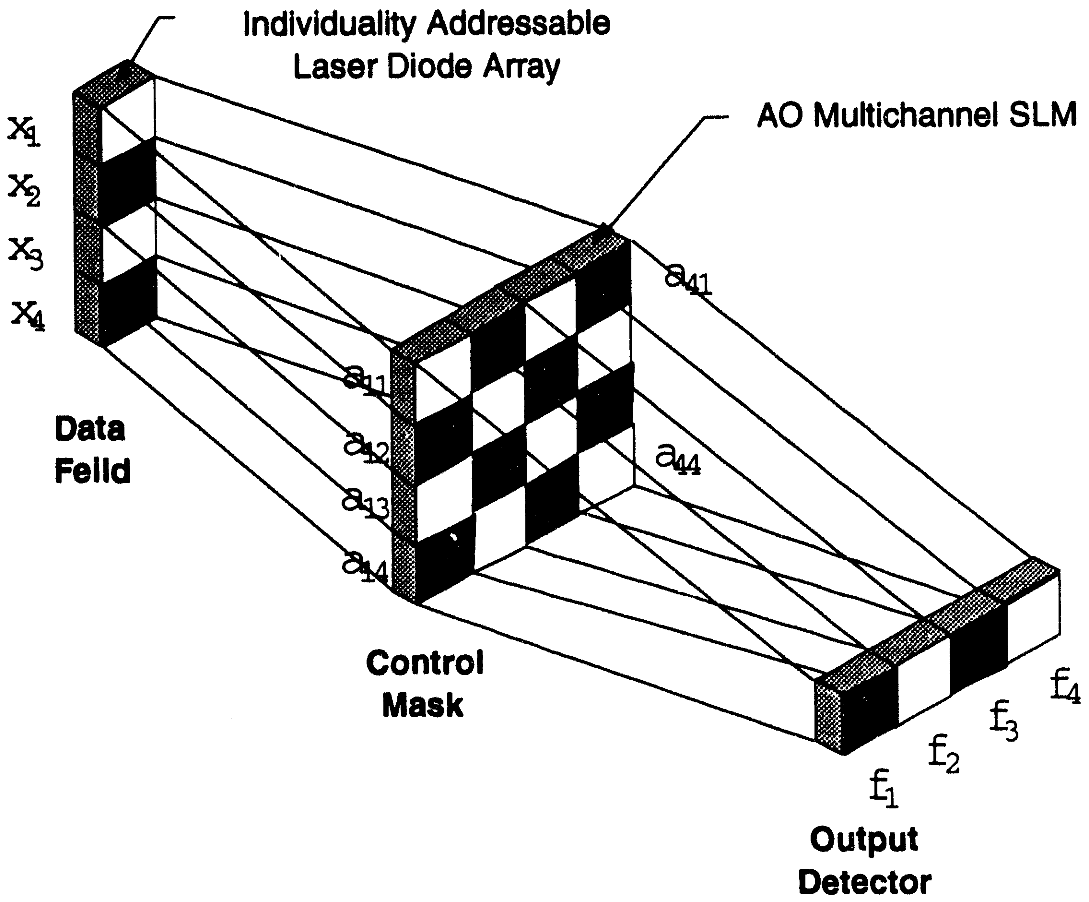

Figure 12. **The Two-Dimensional AO Deflector Approach Has Advantages Over the Planer Approach but for the Application at Hand Is Still Likely Too Large.**

smaller and more efficient but likely still too large for the current application.

S-SEED Switch Array

S-SEED switch arrays do not meet the currently envisioned requirements but are the most interesting reconfigureable switch arrays. This device can perform high-speed optical and electronic logic in massively parallel computer architectures. This architecture allows the data to be input optically or electronically and the data to be clocked and read-out optically. This family of devices promises to build intelligence into reconfigureable switch arrays.

KCD would like to start evaluating a breadboard that would use an optically addressable S-SEED switch array. We would like to pursue this approach to become more familiar with this technology and be positioned to take advantage of and influence the rapid technology development in this area by others, who may not have the interests of the NWC as a priority. This breadboard would be similar to Figure 13.

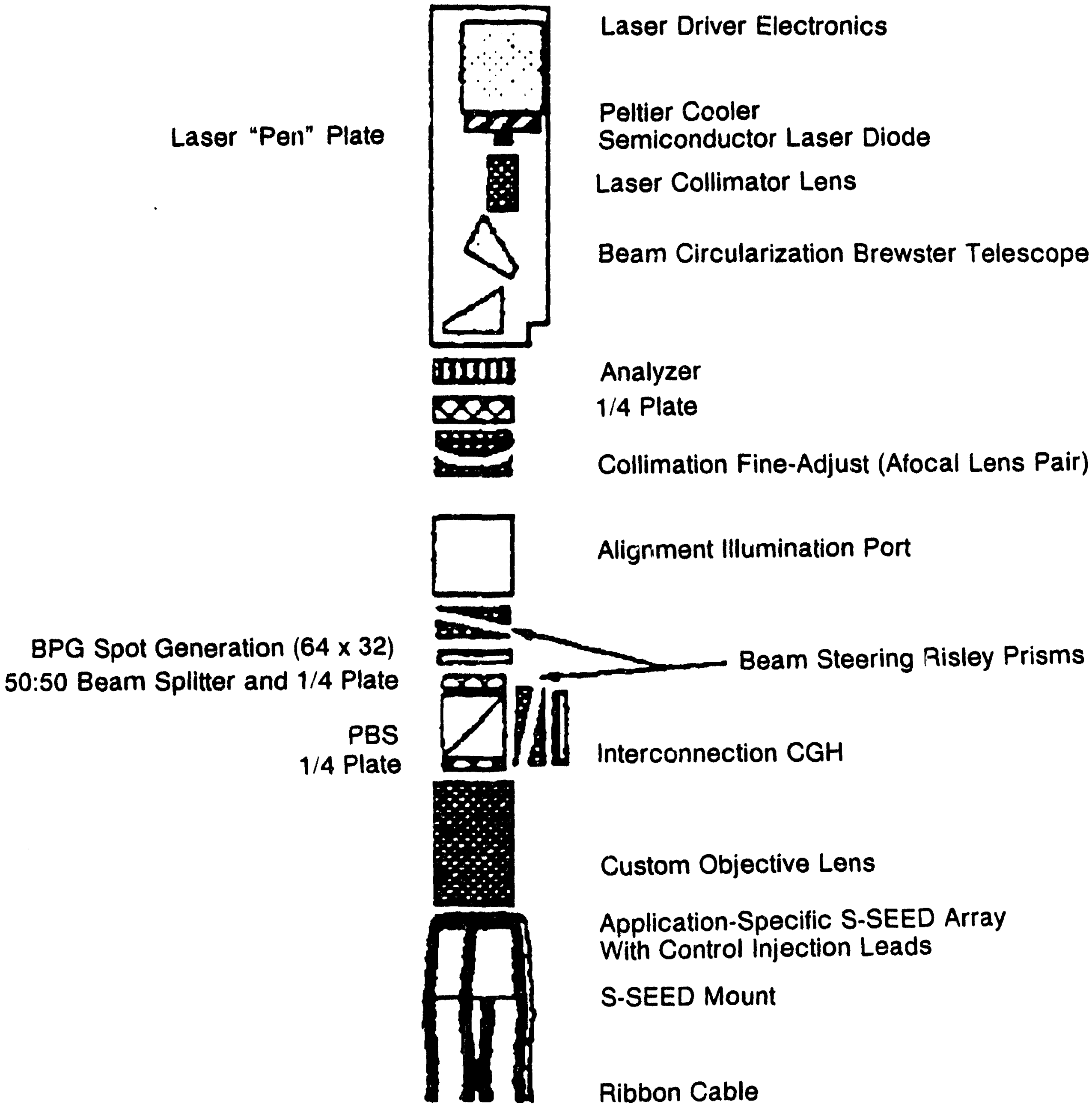

Figure 13. The S-SEEDs Represent Such a Leap in Technology for Optical Switching That Even Though They Are Not Appropriate for This Application, It Is Important to Learn More About Them and Help to Guide Their Development to Address the Interests of the Weapons Complex.

Future Work

KCD recommends that the following activities be addressed.

- Continue to monitor and interact with the technical community to enable the interests of the weapons complex to be represented and allow us to take advantage of the technology breakthroughs.

- Procure and evaluate GaAs active waveguide switch arrays, because they represent the most logical solution to the current application, at present, and may provide relatively short-term solutions. This approach coupled with multimode integrated optic laser amplifiers promises to provide as much as 600 mW of output from these devices using currently available technology.

- Complete our evaluation of the $LiNbO_3$ switch arrays and evaluate laser damage thresholds to determine the practical power transmission capabilities. We would also like to expand this work to include $LiTaO_3$ because this material does not suffer from wavelength-dependent optical damage as does $LiNbO_3$.

- Build an S-SEED breadboard to become more familiar with this technology and be positioned to take advantage of and influence the rapid technology development in this area by others who may not have the interests of the NWC as a priority.

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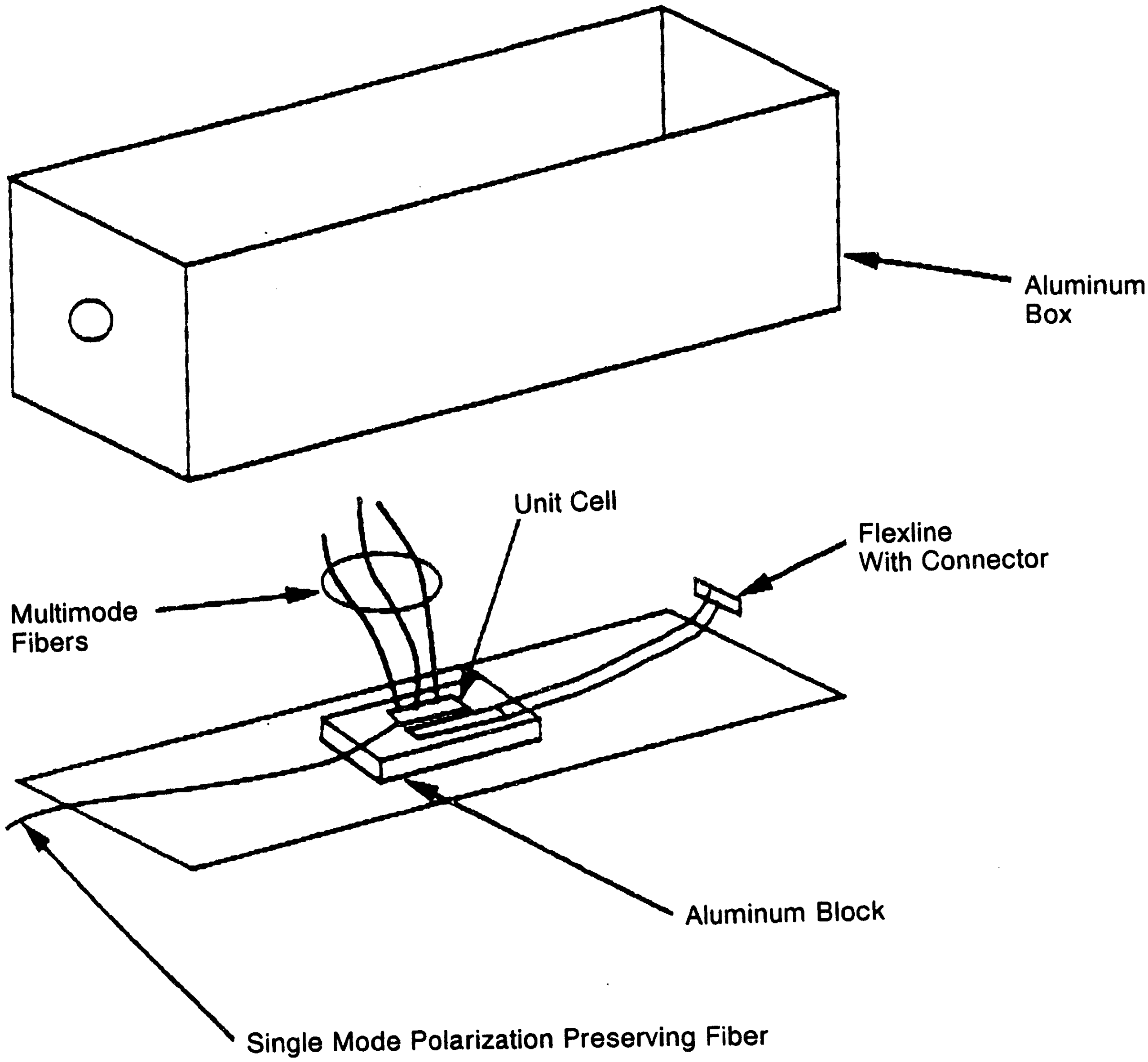
Appendix

White Paper

Proposed Statement of Work

In our meeting on August 5 AlliedSignal expressed interest in a quick turn around, proof of concept, optical amplifier demonstration device. We are happy to submit this proposed statement of work in response. We propose to construct an integrated optical splitter/amplifier with one single mode, polarization preserving optical fiber input and at least two multimode optical fiber outputs. The integrated optical splitter/amplifier will be taken from our inventory of optical phased array devices. These devices are designed to split an incoming signal into ten separate channels, amplify the signal and phase align them. We will only be using the splitting and amplifying properties of the device in this work. However, the phase modulator section can also be used as an amplifier or absorption section. This will allow a demonstration of blocking a signal by reverse biasing individual modulator sections of the device to attenuate one output while leaving others unchanged. We will use a flex circuit to make the electrical connections to the device. A standard electrical connector will be provided to interface the device with power supplies. As an option, simple power supplies for operating the device in a turn-key fashion can be provided. An instruction sheet for proper operation of the device will also be provided. The unit will be housed in an aluminum box with feed throughs to allow the electrical lines and optical fibers to enter and leave the box. The device will not be actively cooled and will be capable of CW operation for limited periods. Pulsed operation (10% duty cycle) for extended periods should be possible. The wavelength of the device will be between 850 and 870 nm. We expect to deliver between three and five devices, depending on the yield of the fabrication process. Estimated delivery would be 4 weeks ARO for the optical splitter/amplifier devices. Delivery for the power supply and control electronics may be longer.



Proposed Device Layout