

# EFFICIENT, HIGH POWER LASER TO MULTI-FIBER COUPLER FOR TRIGGERING OPTICAL ACTIVATED SWITCHES\*

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## Abstract

There are numerous applications requiring multiple high power laser beams. The simultaneous operation of many optically controlled high power switches such as photo-conductive, optically initiated gas, surface, and junction semiconductor requires synchronous delivery of pulsed high power optical energy to many sites.

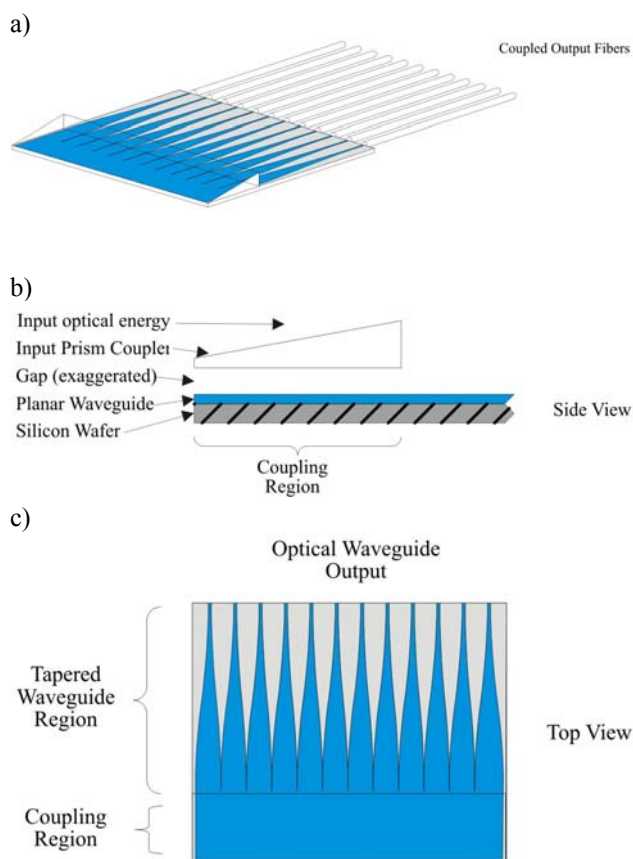
The University of Missouri design presented here avoids the input surface damage that limits other high power division schemes and operates at the peak optical power density of the device materials. This design consists of a prism coupler, planar waveguide, and waveguide tapers fabricated on a silicon substrate. The laser beam will be spatially expanded, focused along one axis using a cylindrical lens or grating, and directed into the prism coupler. The prism coupler allows the optical energy to be coupled into the single highest mode of the planar waveguide. Actual splitting of the optical energy is accomplished by the use of multiple tapered waveguides which are coupled to multimode fibers. Design methodology and simulation results of the proposed design will be presented.

## I. Introduction

Optical fibers are the most practical method of delivering high power optical pulses to many sites simultaneously from a single source. However, conventional approaches for dividing pulsed optical energy into multiple fibers have a limited power capacity and can be inefficient. The power handling capacity is limited by the peak power density in the optical materials and by the damage threshold of the input optical surface. For example, coupling a laser pulse to a single fiber and then branching to multiple fibers can be very efficient but the maximum power density of the first fiber limits the total amount of input power. When using fiber bundles a

percentage of input energy is lost in fiber cladding, reducing the coupling efficiency. These issues have been the motivation for this new design.

In our proposed design the prism coupler will allow optical energy to be launched into the single highest traverse mode of the wide planar waveguide. By limiting the optical energy to the highest mode we can achieve the uniform distribution of power across the waveguide and hence utilize the maximum power handling capacity of the waveguide material. Figure 1 shows the general layout of the proposed design.



**Figure 1.** Proposed layout of power splitter. a) 3D view b) Side view c) Top view

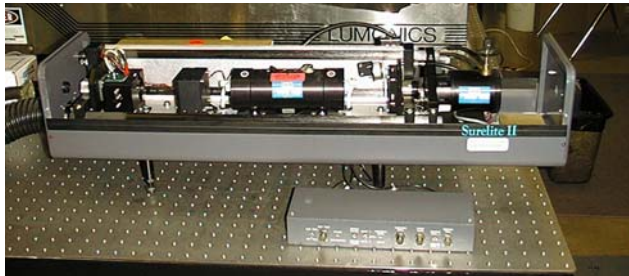
The proposed power splitter will be designed to handle a high energy input laser pulse and evenly distribute the energy into multiple fiber optical cables. Our design specifications are to couple 660mJ of 1.064nm wavelength light from a 40ns pulsed Nd:YAG laser into

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multiple multimode fibers with an even distribution of 5mJ per fiber. **Figure 2** is a picture of the laser to be used in testing the coupler.



**Figure 2.** Surelite II pulsed Nd:YAG laser (660mJ; ~40ns) from Continuum

### A. Power Capacity of Dielectric materials

For optical components there is a maximum power density threshold above which irreversible material damage will occur. This threshold is dependent on manufacturing processes and is due to impurities in the material. Manenkove and Nechitailop [1] described the principal concept in laser induced damage, that being thermal instability. Nonlinear absorption of optical energy leads to localized heating which can cause a number of damaging effects such as internal mechanical stress. The local heating can reach temperatures of  $10^4$  K which has a thermal radiation peak in the UV range. This radiated UV energy can also cause material damage in the vicinity of the localized heating.

At the time of this writing a fabrication facility had not been chosen. Specific details on the power handling capacity of the actually waveguide material to be used is unavailable.

### B. Prism Coupler

The prism coupler design contains several parameters which must be optimized to realize a satisfactory design. [5]-[8] The prism to planar waveguide gap distance, prism coupling length, and beam input angle all have a large impact on the performance of the power splitter. A weak coupling between the prism and waveguides is required so the modes of the waveguide are not altered by the prism. This is accomplished by making the gap sufficiently large as to not change the effective index of the gap but sufficiently small so power can be efficiently coupled into the waveguides from the prism. This gap is typically on the order of a wavelength.

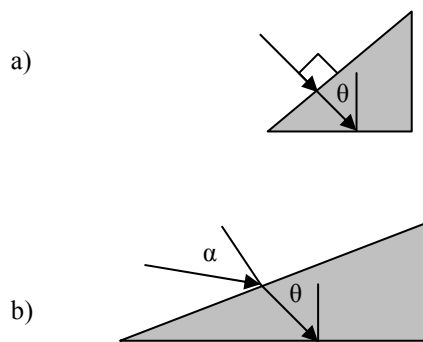
The angle at which the input energy is incident on the gap from the prism must be greater than the critical angle as to induce to total internal reflection. Power is transferred from the prism to the waveguide by the coupling of evanescent fields present in the gap due to the total internal reflection.

An ideal length exists at which maximum power has been transferred to the waveguide. [5]-[8] After this point power is coupled back into the prism. For maximum power transfer into the waveguide it is necessary to terminate the prism coupler at that point. The ideal length

for a given set of parameter has been calculated by Ulrich[7]. At this ideal distance a maximum power transfer of about 81% can be achieved[8]. It was noted by Lee[8] that the coupling efficiency can be increased by using a non uniform gap. However the exact function of the gap distance was not given. The power transfer of a non uniform gap is still under investigation.

### C. Launch Angle

For efficient operation reflections at the input prism face need to be kept to a minimum. Two methods by which this can be accomplished are with antireflection coatings and a beam input angle which is perpendicular to the input face of the prism or by setting the input angle to Brewster's angle. As mentioned earlier the goal is to launch the optical energy into the single highest mode of the planar waveguide. This implies that angle of incident upon the gap between the prism and waveguide should be the same for whatever prism geometry is chosen. The angle of the input prism face needs to be adjusted accordingly to accomplish this task. Figure 3 shows a diagram of the two suggested orientations.



**Figure 3.** Two different configurations of the input prism.

In both cases angle  $\theta$  is identical. a) Input beam perpendicular to prism face. b) Input beam at Brewster's angle ( $\alpha$ ).

### D. Modal Power Capacity

When discussing the power capacity of a waveguide it is important to understand how the power is internally distributed. It is well known that optical energy propagating in a waveguide is distributed across a finite number of modes as opposed to being evenly distributed. Integrating the power density across a cross-sectional area will give the total power flowing across that surface. However the breakdown of dielectric material is based on power density, not total output power. Since the higher modes distribute the fields more evenly across the waveguide cross-section they can support more total power in a given material than the lower modes. This concept was simulated and the results are given below during the discussion of simulation results.

### E. Tapered Waveguides

Once the power has been transferred to the waveguide, it must be distributed into multiple smaller waveguides

which are coupled to multimode fibers. This is accomplished by using a tapered waveguide, sometimes also referred to as a spot size converter, to separate the one wide waveguide into multiple smaller waveguides.

Several methods for designing lossless tapered waveguides have been investigated by varying the waveguide cross-section and index of refraction[2]-[4]. These so called adiabatic tapers allow energy to be transferred between two different size waveguides without any energy being radiated or transferred to higher modes. However variation of the index of refraction throughout the tapered waveguide will complicate the fabrication process. A constant index of refraction throughout the waveguide taper can yield reasonably low power loss if the taper is long and gradual.[3]

## II. Simulation Results

The University of Missouri has recently acquired Optiwave for optical simulations. Optiwave is an optical propagation software package which has several different programs. Each program uses a different method to calculate how optical fields evolve over time. The finite difference time domain (FDTD) and beam propagation methods (BPM) are available to be used. Simulations were run using Optiwave FDTD to investigate the waveguide modal power density, prism coupling, and tapered waveguides designs. However only results for the power density are given because of difficulties encountered in manipulating and interpreting quantitative results given by Optiwave.

Figure 4 is a graph of power density for the lowest and highest modes inside a 2-D rectangular planar waveguide. The geometry of the waveguide is as follows.

Width = 4 $\mu$ m, core index = 1.5, cladding index = 1, wavelength = 1.064 $\mu$ m, input power density =  $3 \times 10^9$  W/m

The total optical power for both cases is identical and the waveguide structure is identical. The only difference is the mode in which the input optical energy was launched. From this figure it is clear that the peak power density for the lowest order mode is about 14% higher than that for the highest order mode. In order to take advantage of the full power capacity of the waveguide it is necessary to launch the optical energy into the highest order mode.

## III. Further Design Considerations

Several aspects of this design are still under investigation that could have potentially large effects on performance. The coupling between the square

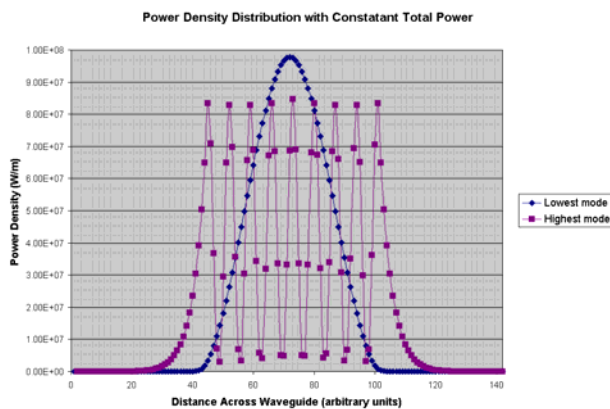


Figure 4. Graph of modal power density as calculated by Optiwave.

waveguide and multimode fiber, and the spatial expansion of the input beam are two critical aspects.

In multimode fibers any bending of the cable will cause optical energy to migrate into different modes or even to be lost in the cladding because the critical angle was exceeded.

So the exact mode in which the optical energy is launched into the fiber from the waveguide is not critical. However we want to make sure to minimize any losses between the coupling of the waveguide and fiber.

The spatial expansion of the input beam is necessary to achieve uniform power distribution across all the output fibers. The effects of the resulting curved phase front on the performance of the prism coupler and tapered waveguides still needs to be analyzed.

## IV. Conclusion

An efficient, high power laser to multi-fiber coupler for triggering optical activated switches has been discussed and important design aspects and parameters have been given. This design will provide a very important component in optically triggered switches because it will greatly simplify the triggering system. Its high power capacity and relatively simple design has potential to well outperform current power splitters.

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