# High Power WDM with Narrow Wavelength Separations

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**Abstract:** We designed and manufactured a high power WDM to enable a high power Raman lasers. We used a custom designed glass processing machine to fuse the WDM. We tested the WDM at 100 W of power with 0.05 dB loss.
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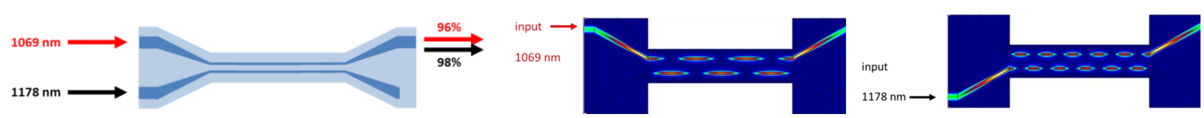
## 1. Introduction

Commercially available WDMs can handle at most 10-20 W of power geared mostly towards telecom applications. However for resonantly-pumped fiber lasers and for high power Raman fiber lasers [1,2] high power WDMs are necessary components. Apart from high power handling capability, WDMs for these applications have to separate/combine pump and signal wavelengths that are close to each other. We used a flame-based custom glass processing machine that has a long travel distance to make extended zone WDMs. Long WDMs are the key to obtain high isolation between narrowly separated wavelengths and adiabatically transfer energy from one fiber to another with low loss and high heat dissipation, thus enabling high power handling capability.

## 2. Modeling of WDM

Our modeling efforts utilized the commercially available software packages Fimmwave and Fimmprop by Photon Design. In the simulations, we used 20/130 μm fiber to pull the taper and side-fuse the fibers to make a WDM suitable for 1069 nm and 1178 nm wavelengths. We chose large mode area (LMA) fibers with 20/130 μm core/cladding diameters so that the WDM device can handle high power. We estimated coupling efficiency of 96% and 98% at 1069 and 1178 nm respectively for a 13.5 cm long waist length and 5 cm long up and down tapers. The overall device length is 30 cm and is shown in Figure 1a. The taper ratio is 5:1. The core diameter at the waist is 4 μm and cores are separated by 26 μm. Figure 1b shows that for the device described above, when 1069 nm is launched into the core of one fiber, say # 1, the 1069-nm laser energy oscillates 3 times between two cores and at the end of the device 96% of the energy remains in core #1. Figure 1c shows that 1178 nm is launched into core # 2 and at the end of the device 98% of the energy is transferred to core # 1 after 5 oscillations. In order to maximize coupling efficiency for both wavelengths it is very important to control the length of the device precisely. With the 30-cm long device, the coupling efficiency is not very sensitive to the length of the waist section. For example, if the waist length is changed by 0.5 cm then the transmission drops only a few tenths of a percentage. With the custom machine we can control the taper length and waist length very precisely to tolerances of < 0.05 cm.




(a) (b) (c)

Fig. 1. (a) Modeling structure of a WDM that has straight, tapered, and waist sections (b) & (c) energy transfer between two fibers at 1069 nm and 1178 nm respectively.

## 3. Manufacturing and testing of WDM

We manufacured the WDMs using a flame-based fusion machine that requires hydrogen and oxygen gas. The temperature and shape of the flame was controled by controlling the gas flows. The machine was progammed to pull the taper and fuse two fibers for the desired lengths. Figure 2a shows pictures of the WDMs at different sections taken by a high resolution camera mounted on the machine. The bottom pictures are cleaved facets at different sections of the WDM. Optimization of the WDM manufacturing process was dependent on the following parameters; gas flow, taper pull velocity, taper ratio, torch velocity, and tension applied to the fibers. We launched 1069 nm light into core # 1 before making the WDM and monitored its power at the other end of the fiber while making the WDM. The WDM manufacturing process was stopped when we monitored three minima and three maxima in the output power of 1069 nm as predicted. We then launched 1178 nm into core # 2 and measured the transmitted power in core # 1. We measured 80% and 75% of transmission at 1069 nm and 1178 nm respectively. This lower-than-predicted transimission suggests that our process needs further optimization.

For testing of the high power handling capability, we built a 100 W fiber laser at 1069 nm. The architecture is shown in Figure 1b. Input # 1 of the WDM was spliced onto the output of the high power laser. An infrared thermal imaging camera was used to look for temperature rise throughtout the entire system. We did not notice any temperature rise in the WDM especially at the waist section up to 55 W of input power. However we recorded a maximum temperature of 85 °C at 100 W of input power. During testing we did not provide heat sink to the WDMs. In the future, we will design a proper heatsink package to remove heat from the WDM. Most improtantly we measured 0.05 dB loss in the device at 100 W.

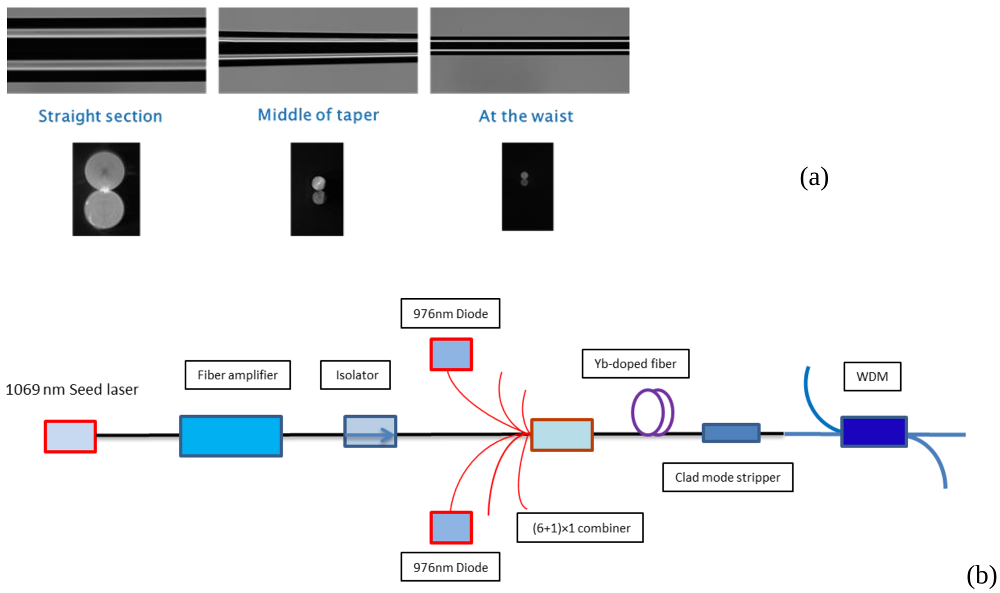



Fig. 2. (a) WDM pictures taken by the high resolution camera on the glass processing machine, (b) schematic of high power laser at 1069 nm.

## 4. Conclusions

We modeled the energy transfer in the WDM and optimized the coupling efficiency for a practical length of WDM. We optimized the WDM manufacturing process and built several units. We tested the WDM at 100 W of input power without any damage. To the best of our knowledge we report the highest power handling capability of a WDM with very low loss. The manufacturing process needs to be refined to improve coupling efficiency and packaging has to improve to remove heat from the WDM.

## 5. Acknowledgements

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## 6. References

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