Optical Isolators Improve Engraving Performance of Pulsed Fiber Lasers

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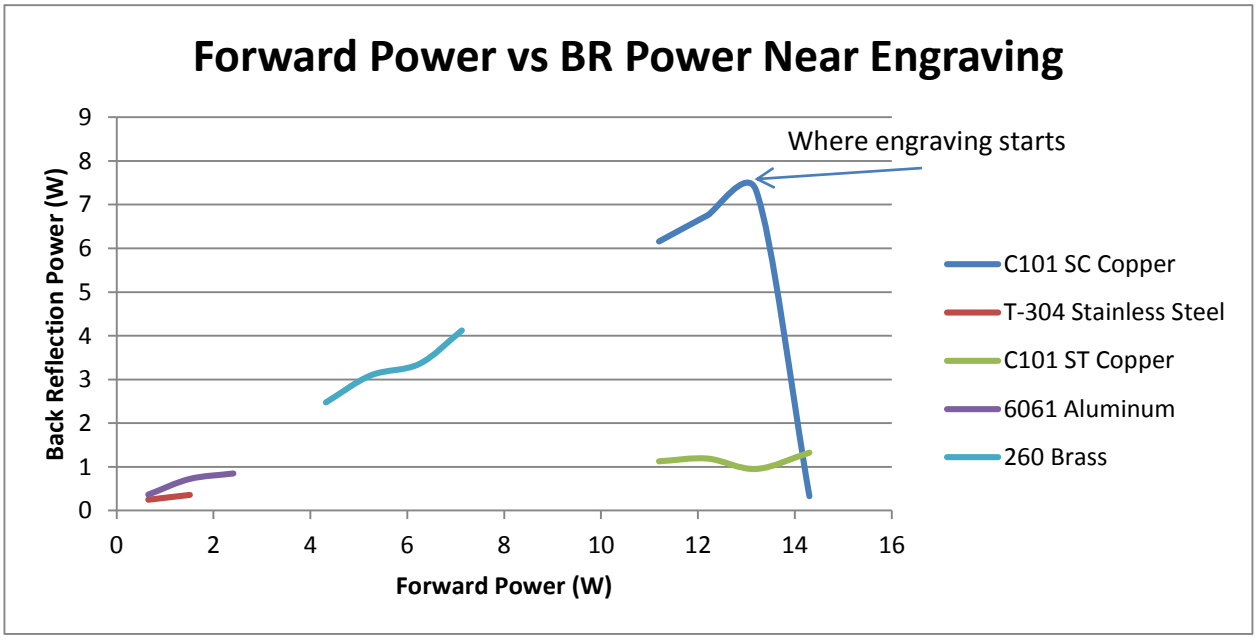
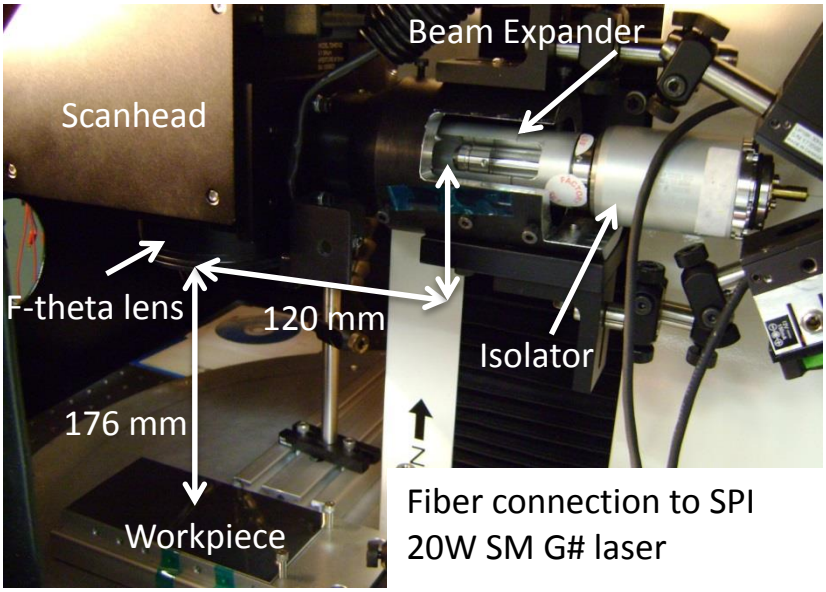
1. **Introduction:** Pulsed fiber lasers have become the primary laser source for the marking and engraving of various metals. The deleterious effects of back reflections from the part being marked or engraved are well-known. These effects include reduced beam quality, poor marking or engraving quality, and damage to the laser itself. As shown in Figure 1, back reflections can reach very high levels, near 90% in some cases. For this reason, optical isolators at the output of the pulsed fiber laser, particularly for average powers ≥20W have become integral parts of pulsed fiber lasers. Further, optical isolators can be exposed to a variety of operating conditions when used with pulsed fiber lasers for marking and engraving. This paper looks at some of those conditions and their impact on optical isolator performance and marking and engraving quality.

Figure 1: Forward Power vs. Back-reflected Power Near Engraving



2. **Test Setup:** Figure 2 is a photo of the test setup used. EOT's 50W and High Energy Optical Isolators were used in the testing. The test laser was an SPI 20W SM G3 laser.

Figure 2: EOT's Test Setup



3. **Test Results:** Tests were conducted on the isolator when the beam was in focus and out of focus.
   - **a.** When marking metals with a focused laser beam there are three main aspects of the laser that affect the quality of the marking: Power of the beam, rep rate of the pulses, and the focus of the beam. To create quality marking there must be enough power to ablate the metal. This is controlled by the average power set point and the rep rate of the pulses. The required power for engraving and the frequency at which engraving stops for various metals is presented in Figure 3. As the rep rate is decreased, the peak power in each pulse increases. Once there is enough power it must be focused down to the smallest spot size in order to provide a power density high enough for material removal. Consequently, the focus of the laser is very crucial to ensure quality marking. If the laser is out of focus, there will be little or no marking on the sample, even if there is enough power to mark the sample.

Figure 3: Required Power and Frequency for Engraving

Material	Power where engraving starts at 35 KHz	Frequency where Engraving stops
C101 SC Copper	13.8 W	55 KHz
C101 ST Copper	14.9 W	50 KHz
T-304 Stainless Steel	6.09 W	100 KHz
6061 Aluminum	5.14 W	65 KHz
260 Brass	10.9 W	65 KHz

The need for a precisely focused beam presents two challenges when dealing with laser light. Initially, when the beam is perfectly focused, the highest amount of light back-reflects off the sample and back into the fiber core. To combat this problem it is necessary to have an isolator that can block the back reflections without overheating, protecting the fiber and laser. The second challenge arises when the beam is out of focus. When this happens the back-reflected beam is larger than the aperture. As a result, the beam expanding components attached to the isolator heat up, which leads to thermal expansion and focal shift. This focal shift issue is discussed more thoroughly below.

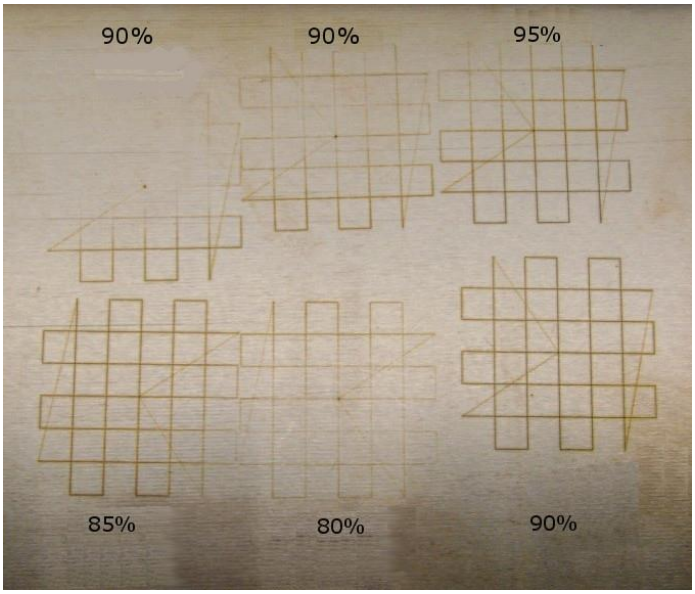
b. When the beam is out of focus, focal shift can become an issue. Focal shift occurs when the back-reflected beam from a sample is too large to cleanly enter back into the isolator and hits the beam expanding components of the isolator, causing an increase in temperature. This can lead to thermal expansion of the beam expanding components which shifts the optics and causes a focal shift. This can have a multiplying effect in focal shift as time passes. The longer the laser is used, the more the beam expanding components will heat up, and the greater the focal shift will be. When a beam is out of focus, engraving may be acceptable initially, but as time passes, the thermal effect will continually decrease the engraving quality. To combat this problem, care must be taken to ensure that the beam is properly focused on the sample to be engraved. Figure 4 shows the difference in temperature of the isolator after three minutes with the laser in focus and then again with the laser out of focus (4mm above focal point). When the laser is out of focus there is a much larger temperature change, which leads to additional defocus and further heating – a possible runaway condition.

Figure 4: Change in Temperature Based on Beam Focus

Isolator Heating	
In focus ΔT	**Out of focus ΔT**
1.6°C	5.1°C

High isolation is important to ensure that the isolator can stand up to engraving even the most reflective metals. In trials of various metals it was found that while the metal is being engraved, the amount of power that comes back to the isolator is relatively low due to the absorption of energy by the metal which prevents back reflection. However, in the small window before engraving starts or if power is too low to engrave, tests have shown that as much as 90% of the forward power can make it back into the isolator when attempting to engrave polished copper. Figure 1 on page one illustrates the forward power vs. the back-reflected power for a variety of metals at power levels just below the threshold of engraving. As can be seen in Figure 5, copper requires the most power to engrave and as a result, has the highest amount of back-reflected power.

Figure 5: Power levels of engraving C101 ST copper at 35 KHz. 90% corresponds to 14.9W



4. **Summary:** It has been demonstrated that back reflections can reach levels as high as 90% of the transmitted power. Further, it has been shown that isolator performance can be impacted whether the laser beam is in focus or out of focus. Therefore, it is important to have an optical isolator that can handle high levels of back reflection whether or not the beam is in focus. EOT's 50W and High Energy Optical Isolators withstood high levels of back reflection under both in-focus and out-of-focus conditions

while maintaining high levels of isolation. EOT Optical Isolators also ensure that the engraving system using pulsed fiber lasers is capable of a wide variety of applications and can withstand the most demanding operating conditions.