Applications Guideline: Photran Sapphire Fibers*

The successful application of fiber optics for high power laser delivery requires careful consideration of a number of factors, including the surface conditions of the fiber, the laser-to-fiber injection method, and the laser characteristics. Without proper attention, any of these factors may induce fiber failure, even in high damage threshold materials like sapphire.

Controlled experiments using Photran fibers have been conducted at the Rutgers University Fiber Optic Materials Research Center, as well as in the Photran laboratory and other field locations. These repeated tests have demonstrated that optimized fiber and laser parameters allow fibers with losses as high as 8 dB/meter to accept input energies over 750 mJ/pulse at 10 Hz. However, fiber failure could be induced in low loss fiber (near 1 dB/meter) with any combination of poor surface finish, poor alignment, or with an input beam containing significant "hot spots". To summarize, a relatively poor fiber can handle very high pulse energies when using a combination of preferred parameters, but even a very good fiber could fail at low input energies due to deficiencies in any of the described parameters.

Series of adjustments are typically made whenever starting up a new laser, when making significant changes to power or rep rate, or in tuning/re-aligning a system after transport or storage. During the course of these adjustments fibers are exposed to a range of challenging conditions. To facilitate the alignment and set up under such conditions, Photran recommends the initial use of the Sapphire fiber alignment and start-up kit. This kit is comprised of five polished, test-ready sapphire fibers (25 cm) and a re-usable SMA connector with a pin-vise fiber mount for securing the fibers in the SMA. The use of the Photran sapphire fiber laser alignment kit facilitates setup, adjustment and optimization of parameters without jeopardizing expensive, fully terminated cable assemblies.

* Photran is a former division of Saphikon, Inc.

photran LLC

gradually increased, at a constant repetition rate, upon initial use (rather than beginning with full application power). This phenomenon, generally described as "beam conditioning", has been indicated to improve fiber laser damage threshold, and improve overall reliability. Photran and Rutgers testing indicates similar behavior with sapphire fibers. The preferred approach recommended is to follow a similar ramping to full application power

Summary

In comparison to YAG and other laser systems, the high power use of fiber delivered Erbium lasers has a fairly brief history, with limited experience, worldwide. Applications are envisioned for certain ophthalmic procedures requiring less than a few millijoules per pulse and for dental and surgical procedures, possibly requiring hundreds of millijoules per pulse at very high repetition rates.

Photran looks forward to working closely with all laser manufacturers and users to support the use of sapphire fibers in these delivery applications. This "applications guideline" is only a start. We welcome your input and guidance to better optimize our fibers and to establish broadly accepted preferred parameters to achieve optimum results. Please forward any comments or questions directly to Anthony Defeo at Photran, or call, toll free at 1-866-578-0300, extension 223.

Acknowledgements

Photran wishes to thank Robert Setchell of Sandia National Laboratory for providing his numerous articles on issues relating to laser induced fiber damage, as well as other applications guidelines, and his helpful support. We also wish to thank Dr. James Harrington and Gwynneth Clarke of Rutgers University for their testing, support and advice.

- XY adjustment of the fiber to maximize energy throughput should be done while maintaining a consistent launch angle at a fairly low power level. The goal should be to align the fiber axis collinear with the incident laser beam. *Independent XY adjustment of the fiber is preferred, while* XY *adjustment of the lens can skew the beam (and alter the launch angle).* Proceeding to full power with a poorly aligned fiber can lead to beam focus on the connector or along the sides of the fiber. Ablated material from the connector can be re-deposited on the fiber, leading to severe localized heating and fiber failure.

- Attention should be given to maintaining the alignment of the incident beam collinear with the fiber axis. Deflection or misalignment of the fiber face within the connector, the fiber mount, or the lens mount can induce unfavorable pitch and yaw which could alter the beam/fiber axial alignment. *Proximal fiber damage may result.*

3. Laser Characteristics

- An attached application article by Robert Setchell of Sandia National Laboratories, titled *"Desirable Laser Characteristics for Fiber Transmission of High Intensity Laser Pulses"* (4 pages) was prepared in support of similar work on Q-switched Nd:YAG lasers. The requirements for successful delivery of Er:YAG laser are similar.

- Ideally, the nature of the beam profile should be understood through the entire range of use. Beam characteristics change dynamically with both increased power and repetition rate. Setchell describes the preferred method for evaluating the beam with use of a beam-profiling unit. If beam-profiling capability is not available then the use of "burn paper" may be helpful to estimate the profile.

- The presence of "hot spots", localized areas of very high power density/high fluence, within the beam profile can increase the probability of laser damage on the fiber surface. *While sapphire has a high melting point and high laser damage threshold, hot spots can contain power densities many times higher than the average power density distributed across the fiber proximal face.* Initial pulse spikes can be difficult to detect, and also may result in very high energies being delivered to the fiber. Small "pits" on the surface of the fiber can indicate the presence of "hot spots" in the beam. Subsequent pulses typically result in total proximal failure, or in features resembling drilled holes down the axis of the fiber.

- Proceeding with high power fiber use while having beam profiles with significant hot spots will most likely result in fiber failure. Corrective actions should be undertaken to improve the beam quality to optimize fiber power delivery and increase fiber lifetime.

- Improved results have been demonstrated in quartz fibers when laser power is

Photran offers the following list of factors and recommendations to be considered in optimizing fiber delivery of laser energy. This is based on our limited experience, along with experience from others in the field. We offer suggestions, but defer to the experience of the user to achieve the preferred conditions regarding laser conditions and laser-to-fiber injection.

1. Fiber End-Face Preparation

- Generally, the better the polish, the greater the power handling and laser damage threshold of the fiber. Sapphire fibers are polished to a sub-micron level with final stage chemical polishing. Scratches or debris on the fiber surface, as well as any sub-surface damage, could increase susceptibility to damage..

- Sapphire is a crystalline, rather than an amorphous material such as quartz and other glasses. Sapphire cannot be cleaved in the same manner as quartz fibers. Sapphire is also much harder than glass fibers. Special materials and procedures are required to prepare sapphire fiber ends.

- A complete procedure is available for sapphire fiber polishing – ***Recommended procedure for handpolishing Photran Sapphire optical fiber*** – which details the use of diamond abrasives in preparing sapphire for high power use.

2. Laser-To-Fiber Injection Method

- For high-power applications, a preferred method for termination is to mount the fiber proximal (input) end in a manner that allows the fiber end to be held in free space. Photran recommends and uses a special SMA 905 power connector configuration that achieves this. This configuration provides a greater tolerance for misalignment, while reducing the problems encountered when coupling directly to the connector end face or epoxy.

- Focusing lens selection should allow for a fairly shallow launch angle (<10 degrees half-angle) to match the acceptance angle of the sapphire fiber. Ideally, the spot size should be maximized without "overfilling" the proximal face of the fiber. Note that the spot size typically increases as the power and repetition rate is increased.

- A preferred approach to focal length adjustment is to begin with the fiber beyond the beam waist (minimum focused spot diameter) – and then adjust focal length by adjusting the fiber towards the beam waist. This approach reduces the likelihood of the minimum focused spot size (and maximum power density) occurring within the fiber.