APP NOTE # 1.0

APRIL 12

DAMAGE THRESHOLD OF FIBER FACETS

This application note describes optical damage of fiber facets in pulsed systems and guidelines are given on the damage thresholds and how these depend on the pulse length. The quoted values might act as a guideline when using our fibers, but it must be emphasized that damage thresholds depend critically on the surface quality of the fiber end-facet and even minor imperfections can decrease the damage threshold by several orders of magnitude.

Optical damage

The conventional description of bulk damage induced by picosecond and nanosecond optical pulses involves field-induced electron avalanches followed by energy transfer from hot electrons to the glass or crystal matrix. The released energy can then cause melting or fracturing. In practice the process is less well-behaved as measured breakdown thresholds can vary by a factor of 100 or more [1]. As a consequence there are conflicting answers on whether the breakdown threshold is statistical or deterministic.

Furthermore it is important to notice that there is a difference between bulk and facet damage. In general facets are more fragile, and irregularities, roughness or dirt on the facet dramatically reduce the damage threshold .

The first step in obtaining high damage threshold is carefully optimizing the polishing process of the facet and ensuring that it is clean.

A thorough overview of the topic has been presented by *A.V. Smith and B.T. Do* [1]. In their study it was shown that by proper polishing the facet damage threshold can be made equal to the bulk damage threshold.

Furthermore it was shown that pulses longer than 100 ps comply with the electron avalanche theory. Thus the damage threshold is deterministic and there is no cumulative damage.

For 8 ns pulses damage in pure silica was found at an irradiance of around 4.1 kW/μm^2.

When decreasing the pulse length with a factor of 570 to 14 ps, the measured damage threshold decreases by a factor of 180. Thus contrary to common belief the damage threshold neither scales with the square-root nor with the pulse length itself [1].

The stated value represents the best case, which will only be obtained for perfect surfaces in pure silica.

Increasing the damage pulse energy

The damage pulse energy scales with the mode area, so fibers with larger mode field diameter can handle higher energies.

Further improvements can be obtained by expanding the beam at the fiber facet e.g. by using an endcap.

There are several methods to prepare the fiber facets. Below is a description of some of these.

Collapsed and cleaved facets

Despite having air holes, photonic crystal fiber can be mechanically cleaved.

In order to obtain the best cleave quality, we recommend collapsing the holes close to the facet prior to cleaving. For cleaving large mode area fibers we recommend using the Vytran LCD- 200-G cleaver. For more information on cleaving please see out application note “Fiber Handling, Stripping, Cleaving and Coupling [2]

The collapse and cleave method leaves a collapsed all glass region close to the facet, see fig.1 below.

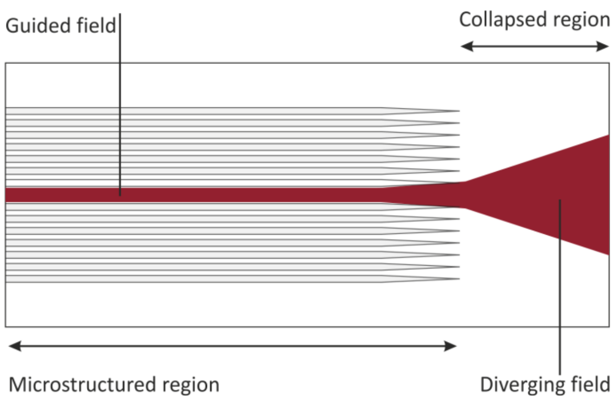


Figure 1: In a fiber with a small mode field diameter the collapse and cleave method leads to beam expansion at the facet.

In the collapsed region the light is unguided and thus diverges, leading to a larger field at the end facet. The divergence angle is inverse proportional to the mode field diameter, and thus the divergence can be large in typical non-linear fibers, while it is normally fairly small in large mode area fibers.

Polished fiber facets

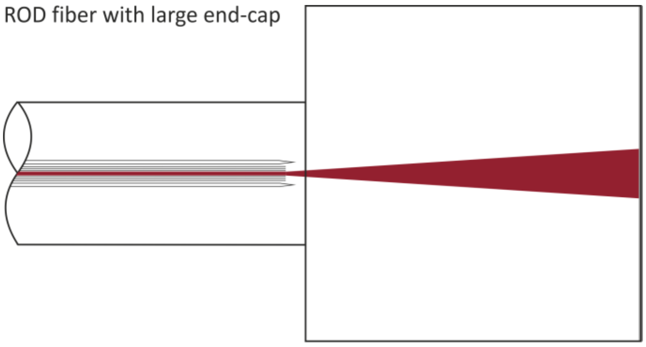
A second option is polishing the fiber facet. Here the fiber is typically hand cleaved, collapsed and polished in several steps to obtain a smooth and clean surface. Polishing enables a large reproducibility of the angles as well as an orientation of the fiber facet.

Endcapped facets

NKT Photonics offers silica endcapping of fiber facets. For flexible fibers the endcap has the same outer dimension as the fiber in order for it to fit into a standard connector. This type of endcap does not provide significant beam expansion but can be polished to high surface quality without risk of breakthrough to the airguide structure. Furthermore it consists of pure silica, which might have slightly higher damage threshold than the doped silica used in active fibers [3].

For ROD fibers a thicker end-cap is also offered in order to decrease the peak intensity on the end facet.

ROD fiber with large end-cap



Flexible fiber with small end-cap

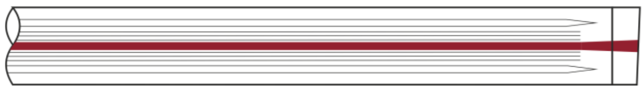


Figure 2: ROD fiber and flexible fiber with end-cap. Note that the short end-cap of the end-cap on the flexible fiber does not provide any substantial beam expansion. The increase in damage threshold obtained with a small end-cap can be contributed only to the purity of the end-cap glass compared to the doped active core.

Keeping the fiber facets clean

Fiber facets must be handled carefully to avoid scratches and contamination. Furthermore it is recommended to use the fiber in a clean environment in order to minimize the risk of contamination by dust particles in the air.

It is a delicate issue to clean fiber facets in high power laser system. The recommended method is dipping a soft cloth in IPA and subsequently sweeping it gently across the fiber facet. Even if this is done carefully there is a risk of leaving particles on the end facet and thus reducing the damage threshold.

It is particularly difficult cleaning the fiber inside a SMA905 high power connector, and this should be regarded as a last resort.

Measured damage thresholds

For passive fibers the facet damage normally occurs at the input facet. For non-linear fibers the damage often occurs at the end of the collapsed region, where the mode field diameter matches the fiber mode.

For active fibers the damage normally occurs on the output facet where the energy is higher. According to *A.V. Smith and B. T. Do* this value is 30% lower than the input pulse energy giving rise to the damage [1].

NKT Photonics measurements

NKT Photonics has performed some measurements of the damage threshold and the results are summarized in table 1 below.

Note: The measurements shown in table 1 represent best case values or hero results. It is not recommended to push the facet to these values. To prevent damage it is recommended having a substantial safety margin to these values.

Product	SC-5.0-1040	DC-200/40-PZ-Yb	DC-200/40-PZ-Yb	DC-200/85-Yb-ROD	femtoWHITE 800
Facet quality	Collapsed and cleaved	Polished end-cap	Collapsed and polished	Collapsed and polished	Collapsed and polished
MFD	4 µm	29 µm	29 µm	60 µm	1.6 µm
Spot size	30 µm	30 µm	30 µm	60 µm	20 µm
Wavelength	1064 nm	1064 nm	1064 nm	1064 nm	800 nm
Pulse length	1.2 ns	10 ns	1 ns	10 ns	~100 fs
Facet	Input	Output	Output	Output	Input
Measured damage threshold	15 µJ	1.2 mJ	~1 mJ	3-4 mJ	~10 nJ

Table 1: NKT Photonics measurements of damage threshold on some of our fibers.

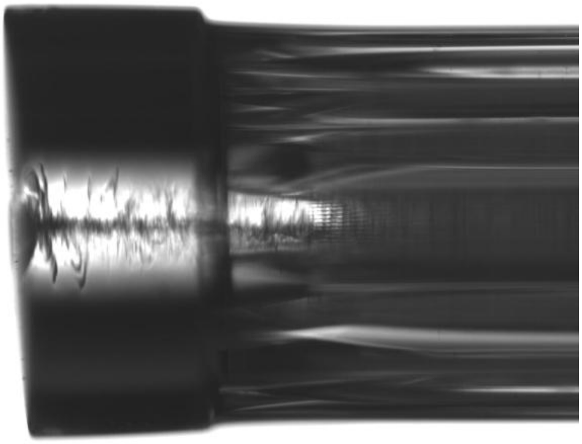


Figure 3: Side view of damaged fiber facet on a polished endcap.

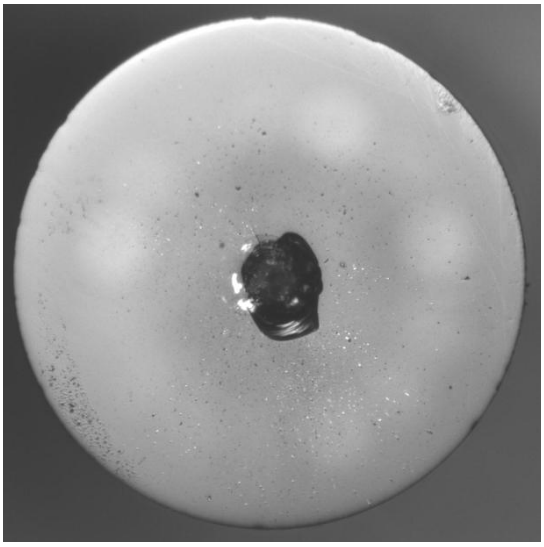


Figure 4: End view of a damaged facet

It should be noticed that there can be other damage mechanisms than facet damage. Examples include internal damage inside the fiber (fiber fuse) due to defects and interface damage between the fiber and endcap.

Typical causes of failure

Self-pulsation in a laser setup:

In a laser set-up it is important to have sufficient feed-back to the cavity to maintain lasing and clamp the optical gain. Typically at least 5-10% reflection is needed. If the feed-back is temporarily reduced, the gain will increase to very high levels, and the stored energy can self-release and cause irreversible damage to the fiber.

Release of energy in an amplifier:

In an amplifier configuration it is critical to have sufficient input signal when activating the pump lasers. A pumped and unseeded fiber will store enough energy to destroy the fiber via self-pulsation (Q-switching). This can happen within milliseconds. These pulses can have very high peak power, and can damage both fiber facets and other equipment.

SBS pulses:

Stimulated Brillouin scattering can be a problem when amplifying long pulses (typically >1 ns) in long fibers. In order to avoid this it is recommended to calculate the SBS thresholds of the system and monitor the system for SBS while increasing power. This can be monitored using a tap coupler with a backward port or using the backward port on a free-space isolator.

References

1. A. V. Smith and B. T. Do “Bulk and surface laser damage of silica by picosecond and nanosecond pulses at 1064 nm” Appl. Opt. vol. 47, No. 26, page 418-4832, Sept 2008

2. NKT Photonics application note “Fiber Handling, Stripping, Cleaving and Coupling”

3. A. V. Smith *et al* “Optical Damage Limits to Pulse Energy from Fibers” IEE J. Select Top. Quan. Electron. vol. 15, No. 1, page 153-158, Feb. 2009