

## **Optical Fibers for High Power Medical Laser Applications\***

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### **Introduction**

The use of silica-based optical fibers has greatly expanded the application of medical laser treatments in the wavelength range of 300nm to 2.1  $\mu\text{m}$ . Although there are many fiber designs available to the system designer, a few general designs have fallen into most common use. This is a general review of the most common designs utilized in high power medical applications in this wavelength range.

### **General Fiber Types**

The most common silica-based fiber designs utilized in high power laser medical applications are:

#### **Type I. Silica Glass Core/Polymer Cladding:**

The key features of this type are:

- Good power capability
- Higher fiber NA (0.30 – 0.48)
- Lower cost
- Wavelength range: 450 – 1100nm
- Temperature range: -65 to +125 °C (depends on polymer type)
- Typical fiber sizes:
  - o Core diameter: 300 – 1000  $\mu\text{m}$
  - o Plastic clad diameter: 330 – 1035  $\mu\text{m}$
  - o Buffer diameter: 650 – 1400  $\mu\text{m}$

This is a very cost effective and robust fiber design. Having a plastic cladding significantly reduces the cost of the fiber over a doped silica clad fiber (see types II and III below) at the expense of lower power capability and some reduction in wavelength range. The plastic cladding material can be a fluorinated (hard) polymer or a silicone material. This fiber type is made with a final extruded buffer (jacket) material typically of ETFE, nylon, or PFA. This outer buffer is easily mechanically stripped. The plastic cladding can either be stripped or left in place depending on the requirements of the specific laser conditions.

#### **Type II. Silica Glass Core/Doped Silica Glass Cladding:**

The key features of this type are:

- High power capability
- High temperature (-65 to >300 °C with polyimide coating)
- Smaller cross section
- Wavelength range: 190nm – 2.1 $\mu\text{m}$
- Fiber NA: 0.11 – 0.26 (0.22 is most common)
- Typical fiber sizes:
  - o Core diameter: 200 – 600  $\mu\text{m}$
  - o Glass clad diameter: 220 – 660  $\mu\text{m}$
  - o Buffer diameter: 250 – 690  $\mu\text{m}$

Utilizing a doped silica cladding greatly improves the power handling capability and wavelength range of this fiber over a plastic clad (Type I) fibers. However the silica doping process is more expensive resulting in a significant increase in fiber cost (2 – 5X depending on the fiber size). This type will typically have a polyimide coating applied. The polyimide can withstand >300 °C (up to 400 °C), and therefore this fiber type is the highest temperature option of the three types presented here. The polyimide is also a very tough material and therefore no additional buffer coating is required. This can dramatically reduce the cross sectional area as compared to equivalent core sizes of either Types I or III which require the addition of a relatively thick extruded buffer. The polyimide coating can be difficult to remove and it is often recommended to connectorize leaving the polyimide in place. Note this design tends to be more forgiving in regards to alignment to the laser beam and edge quality of the fiber endface as compared to Type I. This is due to the cladding being a glass material instead of a plastic.

### **Type III: Silica Glass Core/Doped Silica Glass Cladding/Secondary Polymer Cladding:**

The key features of this type are:

- High power capability
- Mechanically robust
- Secondary cladding
- Wavelength range: 190 – 2.1  $\mu\text{m}$
- Fiber NA: 0.22 – 0.26 (on primary cladding) / 0.30 – 0.48 (on secondary)
- Temperature range: -65 to +125 °C
- Typical fiber sizes:
  - o Core diameter: 200 – 800  $\mu\text{m}$
  - o Glass clad diameter: 220 – 880  $\mu\text{m}$
  - o Plastic clad diameter: 250 – 910  $\mu\text{m}$
  - o Buffer diameter: 500 – 1400  $\mu\text{m}$

This design takes advantage of some of the features of both the Type I and Type II designs. Again, utilizing a doped silica cladding greatly improves the power handling capability and wavelength range of this fiber over a plastic clad (Type I) fiber with a cost similar to the Type II. The secondary plastic cladding is intended to guide a portion of the laser power that leaks from the glass core when the fiber is routed around bends. This light may still eventually be lost, but it will be lost over a longer fiber length, thereby spreading out the heat dissipation more safely over a larger area. In some cases the higher NA of the secondary cladding helps to improve power coupling efficiency at the laser launch end. As with the Type II, this design tends to be more forgiving in regards to alignment to the laser beam and edge quality of the fiber endface. The secondary plastic cladding is often removed at the input end, leaving just the glass core and glass clad. This is to reduce the chance of burning near the fiber endface (the polymer being more susceptible to burning as compared to the glass material).

### **Selecting the Right Fiber for Your Application**

There are of course many themes and variations within each of the three types presented. When trying to determine which fiber is right for your application, the following information will help to narrow down the choices:

1. Laser launch characteristics
  - a. Input NA (laser output NA)
  - b. Spot size
  - c. Power level/Power density



2. Wavelength(s) of operation
3. Minimum bend diameter requirements
4. Environmental characteristics
  - a. Temperature extremes and duration
  - b. Any possible chemical exposure
5. Biocompatibility requirement
6. Sterilization method
7. Cost targets (for base fiber and finished assembly)

Discussing the above and any other particular requirements with your fiber supplier will help you to more quickly converge on the right fiber design for your application.

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