

# Square Formed Fiber Optics for High Power Applications

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*Proceedings of the Fourth International WLT-Conference on Lasers in Manufacturing, Munich, June 2007*

## Abstract

Up until recently the core geometry of fiber optics have almost exclusively been circular. With new possible geometries, fiber optics is now not only guiding the laser beam to the work piece but also actively forming the beam shape. Square formed fiber optics is specially aimed for high precision work where the beam shape is critical. Our experimental results show that highly square formed imaging with uniform power distribution can be achieved with a  $600 \times 600 \mu\text{m}^2$  core fiber. The power handling of these fibers is comparable to circular core fibers. With new square geometries we suggest a modified definition of the Beam Parameter Product (BPP).

**Keywords:** Fiber Optics, Square Formed Fiber, High Power Applications, BPP.

## 1 Introduction

The use of fiber optic cables in bringing laser power from the laser to the work piece is today a standard procedure. Up until recently the geometry of the fiber core has almost exclusively been circular. With new geometrical possibilities, fiber optic cables is not only transporting the laser light to the work piece, but can also take an active part in the system design, for example reducing the need for beam shaping optics.

A square formed fiber core delivering a square formed beam is attractive in various high power applications.

In surface treatment with or without mask a square formed beam is often requested. Having a squared image of the laser light directly on the work piece, step and repeat manufacturing is easily implemented.

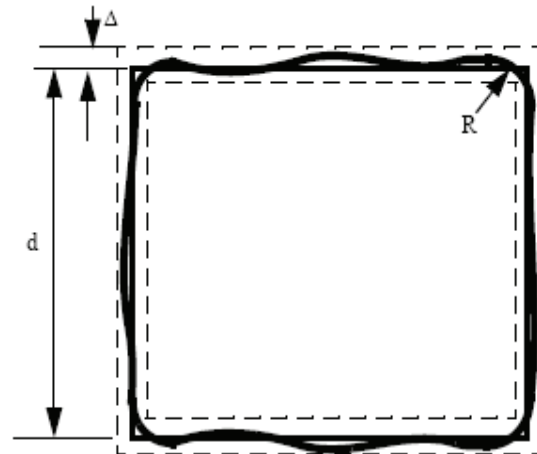
A square shape is useful when coupling light from a diode laser. Due to the often inherently square formed shape of diode laser output, a square formed fiber will couple light more efficiently, thus reducing leakage into the fiber cladding and opening for reduction in the fiber core size.

A square formed beam can potentially be useful in welding and heat treatment applications. This due to the fact that a square formed beam will treat the material more uniformly as it moves laterally along the surface compared to a circular beam.

In this paper we report on the performance of Optoskand QB fiber optic cables with square formed

core and make some comparison to standard circular core fibers. We also suggest a modified definition of the Beam Parameter Product (BPP) for square formed core fibers.

## 2 Experimental Performance



*Fig. 1: Dimension of square formed fiber core*

### 2.1 Square formed fiber specifications with form tolerances

The optical fiber is a step index fiber with a core of pure silica and an F-doped silica cladding. Presently available core sizes are  $600 \times 600$ ,  $800 \times 800$  and  $1000 \times 1000 \mu\text{m}^2$ . The shape of the square fiber core is defined in Fig. 1. The dimension  $d$  has a tolerance of  $-0/+5\%$  (typically  $1\%$ ). Furthermore  $\Delta/d < 5\%$  and  $R/d < 10\%$ , where a typical value of  $R/d$  is below  $2\%$ .

## 2.2 Alignment tolerances

With square formed fibers an extra dimension in orientation is introduced – the square formed core relative the QB bayonet. This is shown in Fig. 2. The tolerance of  $\alpha$  is  $\pm 100$  mrad.

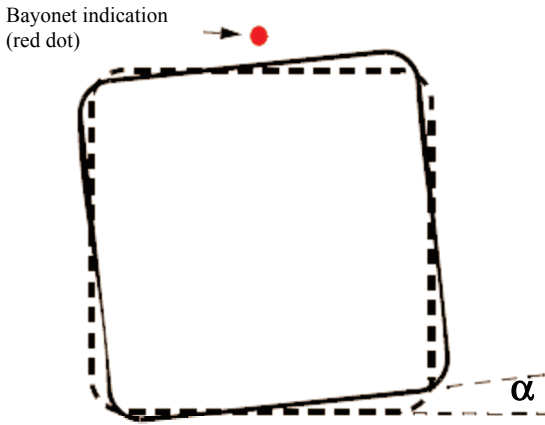


Fig. 2: Orientation of square formed core relative the QB bayonet

## 2.3 Imaging performance

For the experiment a Rofin DY044 at 2 kW (CW) was used. The laser light from the source was focused down and fed into a QBH fiber optic cable with  $600 \times 600 \mu\text{m}^2$  core fiber, see Fig. 3. The numerical aperture (NA) of



Fig. 3: QBH fiber contact

the beam before entering the fiber was 0.11. At the exit side of the fiber an f120 mm collimator and an f200 mm focusing unit, both with quartz optics were employed. Using a Focus Monitor from PRIMES, the beam profile was measured.

The results at various focal planes are shown in Fig. 4-6. We note that the beam shape is highly square formed in focus with low ellipticity. As we leave the image plane by moving out of focus the beam shape becomes more and more circular, showing an even angular distribution of the fiber output. In focus the size of the image at 86% power level is approximately  $1000 \times 1000 \mu\text{m}^2$ , which considering the magnification of

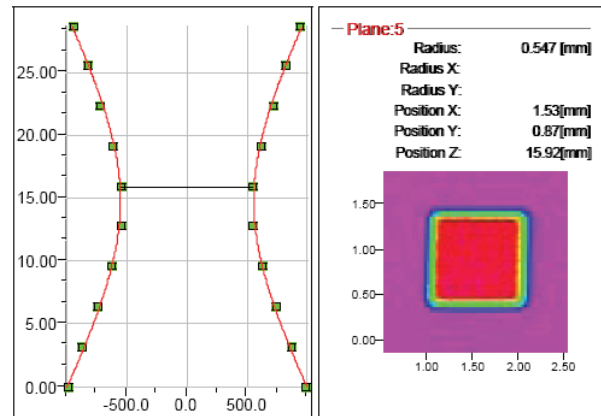


Fig. 4: Beam shape in the focal plane

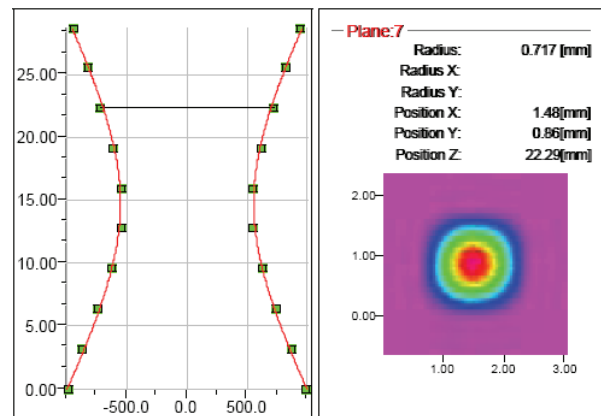


Fig. 5: Beam shape 6.4 mm out of focus

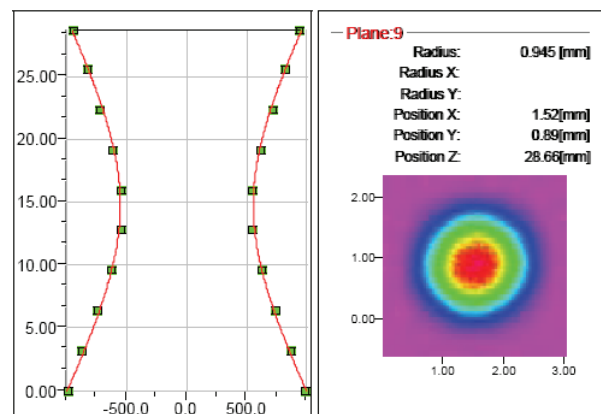


Fig. 6: Beam shape 12.7 mm out of focus

the focusing optics corresponds to  $600 \times 600 \mu\text{m}^2$ . As a comparison we also measured a circular fiber with  $600 \mu\text{m}$  fiber core. Its beam shape in the focal plane is shown in Fig. 7.

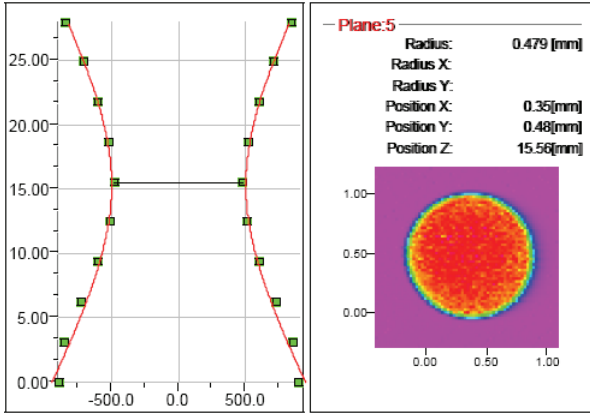


Fig. 7: Beam shape in the focal plane for a circular fiber core

#### 2.4 Power handling and power distribution

Regarding power handling the square formed fibers are comparable to fibers with circular diameter. Thus a  $600 \times 600 \mu\text{m}^2$  core fiber can handle mean power  $> 4 \text{ kW}$ , and peak power max  $10 \text{ kW}$  at  $10 \text{ ms}$  pulse length,  $50 \text{ kW}$  at  $1 \text{ ms}$  pulse length or  $1 \text{ MW}$  at  $50 \text{ ns}$  pulse length. The power distribution in the focal plane tends to be a uniform top hat distribution, as shown in Fig. 8.

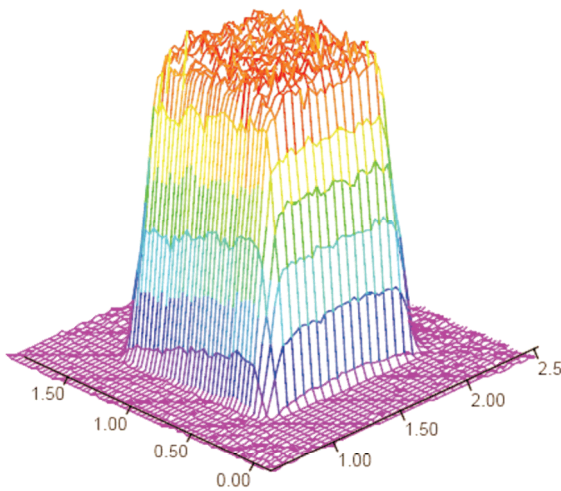


Fig. 8: Power distribution in the focal plane

The RMS roughness over the top hat is approximately 4%. The radius of the corners is small, well below the tolerance  $R/d < 10\%$ . Comparing this to a fiber with circular core, as shown in Fig. 9, we note a similar top hat power distribution in the focal plane. The circular-core fiber also has an RMS roughness of about 4%.

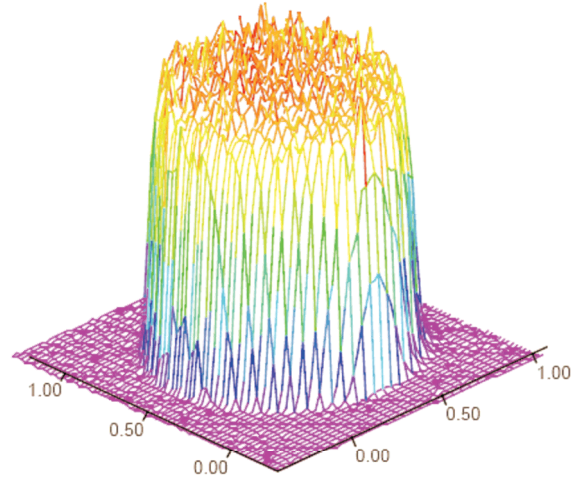


Fig. 9: Power distribution in the focal plane for a circular fiber core

### 3 Discussion

#### 3.1 Definition of Beam Parameter Product (BPP)

With new non-circular geometries of the fiber core we need a modified definition of the Beam Parameter Product. The common definition of the BPP is:

**BPP:** Defined as the product of the beam radius (measured at the beam waist) and the beam divergence half-angle (measured in far-field). [mm\*mrad]

We suggest that for square formed fiber cores the beam radius in the BPP calculations is replaced by the side of the square divided by 2. Thus the new definition would be:

**BPP (Square Formed Fiber):** Defined as the product of half the beam square side (measured at the beam waist) and the beam divergence half-angle (measured in far-field). [mm\*mrad]

With this definition the  $600 \times 600 \mu\text{m}^2$  core fiber with measurements shown in Fig. 4-6 exhibits a BPP of  $28.2 \text{ mm} \cdot \text{mrad}$ .

### 3.2 Fiber dimensions

With fiber core dimensions  $600 \times 600 \mu\text{m}^2$  a uniform and highly square formed beam shape can be focused on the exit side of the fiber. As these dimensions ( $d \times d$ ) are reduced the geometry will keep its square shape, since  $R/d$  is constant. Though, a smaller square might form a less uniform power distribution due to a fewer number of supported lasing modes.

### 3.3 Fiber alignment

As mentioned in 2.2, with a square formed fiber an extra dimension in orientation is introduced – the square formed core relatively the QB bayonet. In applications such as surface treatment without masks it is of vital importance that the alignment of the fiber is correct. Optoskand has products to compensate for the tolerance of the fiber core orientation mechanically by using a special square fiber QB bayonet.

## 4 Conclusions

In conclusion, we have shown results using fibers with square formed cores specially aimed for high precision work where the beam shape is critical. Our experimental results show that highly square formed imaging with uniform power distribution can be achieved with a  $600 \times 600 \mu\text{m}^2$  core fiber. The power handling of these fibers is comparable to circular core fibers. With new square geometries we suggest a modified definition of the Beam Parameter Product (BPP).