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# Holding arrangement for end polishing of single mode and other optical fibers

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**This paper presents a novel approach to polishing the end face of optical fibers including single mode fibers. Single mode fibers, due to having small diameters, are cumbersome to hold while polishing against the grinding wheel. The main challenge has been to hold the end face firmly while polishing. Solution to hold it is presented in this study using locally available materials and capillary tubes. The main ingredients used for holding the fiber are capillary tube, due to capillary action, and the sealing wax. Excellent results were achieved and the results were confirmed and are presented in the form of improved coherence length and beam quality.**

***Keywords:*** *optical fiber, laser beam, end face polish, capillary action.*

***OCIS codes:*** *060.0060, 060.2310, 060.2340, 060.2400, 060.2430.*

# Устройство закрепления торцевых поверхностей при полировке одномодовых и многомодовых оптических волокон

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**Представлен новый подход к полировке торцевых поверхностей оптических волокон, включая одномодовые волокна. Малость диаметров одномодовых волокон затрудняет жёсткую фиксацию их торцов по отношению к полировальнику.**

**Предложен способ, позволяющий решить эту проблему с использованием доступных материалов (уплотняющего воска) и капиллярных трубок, причём фиксация волокон внутри трубок достигается за счёт всасывающих уплотняющий материал капиллярных сил. Экспериментально получено существенное улучшение оптических свойств волокон — увеличение длины когерентности и качества выходного излучения.**

***Ключевые слова:*** *оптическое волокно, лазерный луч, полировка торцевых поверхностей, капиллярная сила.*

## 1. INTRODUCTION

A variety of optical fiber is available on the market. These optical fibers range with respect to their quality, performance and diameters. Multi-mode fibers do have thicker outer diameters as compared to single mode fibers. The range pertains from 50–100 μm, therefore the launching of light in these is relatively easy [1, 2]. Whereas, single mode fibers are finer in diameter and having diameters in the range from 8.3 to 10 μm, whence launching of light waves in these fibers are complicated. Preston has presented and discussed a range of mathematical equations which inter-relate pressure applied to fiber with material removal rate and the surface of work piece [3]. Since single mode fiber are mostly associated with interferometric applications, where basic characteristics of beam are very important. Any slightest angle created at the end face of single mode fiber may make the launching very difficult. These errors enormous back reflections and distortions in the output beam. This angle may also cause the emerging beam cumbersome in terms of beam waist and its quality with respect to coherence length and power due to back reflections [4, 5] which also affects the polarization of the light launched in the fiber [6]. Instead of physical polishing chemical processes has also been relied upon to give various shapes to fiber ends for example tapering and polishing etc. [7, 8]. Therefore, it is necessary and recommended that both the end faces in case of single mode optical fiber are polished. As a pioneer in a related work Konrad et al [9] computed nonlinear losses for various channels. A variety of professional polishing and lab versions of devices are available on the market [10]. However, they are not feasible in cases when only few end faces are to be polished. These cases include researchers and small scale commercial applications. Also, for certain applications, polishing is not feasible [11] as compared to cleaving only due to the stresses caused on the fiber end. Long-Chang et al [12] used commercially available machines to polish optical fibers and compared the stresses developed on the end faces. The method which is presented in this paper is effective and cheap but at the same level as compared to that carried out using devices which are commercially available. Thick walled capillary tube has been used in this study to develop a holding arrangement for optical fiber so that end face of the fiber can be held firmly against the grinding wheel. In order to achieve this arrangement a solid lock and confinement arrangement of optical fiber inside a capillary tube has been developed and discussed in this paper. Therefore, solid material with low melting point is suggested for locking purposes of optical fiber. While in molten state the material rises in the capillary due to capillary action and solidifies itself due to fall in temperature.

## 2. CONSTRUCTION AND CLASSIFICATION OF OPTICAL FIBER

The construction of an optical fiber is such that a core with a particular refractive index value $n_1$ and diameter $d_1$ is surrounded by a sleeve (or cladding) of diameter $d_2$, which has a refractive index value $n_2$ slightly lower than that of the core. The function of the cladding is to support the core against physical impacts, to reduce optical losses due to radiation into the surroundings and to provide a suitable environment in which the phenomenon of total internal reflection can occur.

The refractive index of a medium is defined as the ratio of the velocity of light in vacuum to the velocity of light in that particular medium. To understand the propagation of light waves in an optical waveguide, it is necessary to take account of the refractive indices of the waveguide. In Fig. 1a, a ray of light is shown which travels from a dense medium (e.g. silica) to a less dense medium (e.g. air), making an angle of incidence $\theta_i$ with the normal to the interface between the air and silica, and having an angle of refraction $\theta_r$ into the air. As this light is transmitted through and refracted at the silica–air interface, a part of it is also reflected back, as shown in Fig. 1a.

If the angle of incidence is increased, the angle of refraction will also be increased and the refracted ray will be bent away from the normal until, at some stage, it emerges parallel to the silica–air interface as shown in Fig. 1b. This is the limiting case and the corresponding angle of incidence is now called the critical angle $\theta_{ct}$. This situation can easily be explained using Snell's law [see, for example, Lipson & Lipson (1969)] which can be expressed as

$$\sin\theta_i/\sin\theta_r = n_1/n_2, \tag{1}$$

where $n_1$ is the refractive index of silica and $n_2$ the refractive index of air. Increasing the angle of incidence beyond the critical angle $\theta_{ct}$, no light is transmitted through the surface (i.e. refraction cases) and the ray of light is totally internally reflected as shown in Fig. 1c. This phenomenon of total internal reflection forms the basic model by which the propagation of light in optical fibers is explained.

Consider the core of a fiber surrounded by cladding. Providing that the light is launched into such a fiber core, at an angle of incidence less than the critical angle for the core-cladding interface, then the light will propagate inside the waveguide by means of a series of total internal reflections at the core

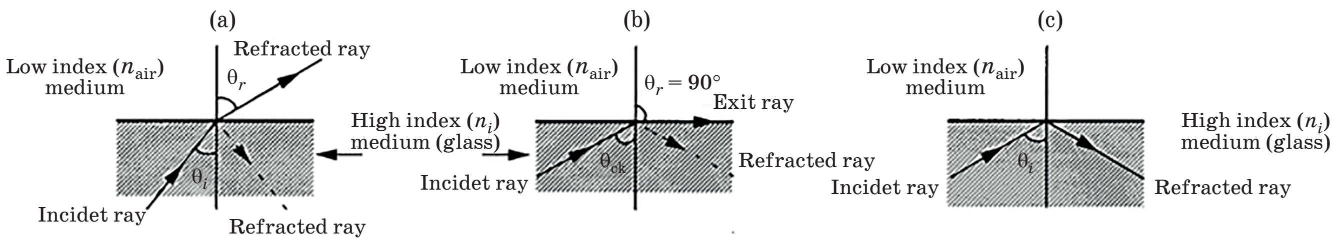


**Fig. 1.** Principle of total internal reflection.

cladding interface. Reference to Fig. 1c will show that a ray which is incident at an angle less than the critical angle $\theta_{ct}$ will transmit a substantial fraction of its energy into the cladding and will eventually decay.

Optical fibers are mainly classified with respect to their construction and propagation characteristics. Thus, the name of each class is characterized by reference to the refractive index profile of the fiber and the number of “modes” capable of propagating simultaneously through the fiber. The two main types of fiber which currently exist are referred to as step-index and graded-index fibers.

(i) “Step index” fiber may be subdivided into step index multi-mode and step-index mono-mode fiber.

(ii) “Graded index” fiber may be subdivided into graded index multi-mode fiber and graded index mono-mode fiber.

For step index fibers the refractive indices of the core and the cladding are constant throughout the two regions but different, so that a step change exists at the core-cladding interface, as shown in Fig. 1a.

In case of graded index fiber, the refractive indices of the core and the cladding do not show a step change at the core-cladding interface. Rather, there is a gradual decrease in the refractive index of the fiber from a maximum value at the centre of the core to a minimum at the boundary of the cladding, as shown in Fig. 1b. Thus, present lower inter model dispersion as compared to step index fiber.

## 3. THE CAPILLARY ACTION

The capillary action is a result of cohesive and adhesive forces due to which liquids may ascend in to slim columns or tubes, whereas, these forces occur between the walls of the tube and the liquid itself. The ascending condition is met when the molecular bonding of the liquid is substantially lower as compared to the substance of tube, hence giving rise to capillarity action. The capillary action has been currently used in enormous number of natural processes such as plantation, human and animal bodies. However, it is also exercised by researchers in applications such as study of porous media [13, 14], radiant heating and cooling and crystallization of compounds [15] etc.

## 4. RESTORING COHERENCE BY CONVENTIONAL METHODS

Cleaving of optical fiber play an important role to maintain coherence length, size and shape of spot size in case of a laser. Diverse methods are widely used to achieve the needful:

- Score and break method.
- Cleaving the fiber using standard cleaving tool.
- Application of index matching gel at the end face of fiber.
- Polish the fiber end so the axis of symmetry and the end face are orthogonal.

### 4.1. Score and break method

This is comparatively more plausible method but for multi-mode fibers. This is due to the reason that multimode fibers are bigger in diameter as compared to single-mode fiber. However, utility of such fiber is not feasible in applications where coherence length is important. Cleaving single mode fiber using this method demands extra care towards score and break process. Moreover, once score and break process is completed, there stands a need to inspect the end face with the help of a microscope for confirmation of the result.

### 4.2. Cleaving the fiber using standard cleaver tool

This is one of the options by using commercially available cleaver tool. This is a better option as compared to free hand cleaving; however, it causes back reflections into the laser cavity due to silica crystals at the end face, as these start acting as lenses.

### 4.3. Application of index matching gel

Improvement in terms of coherence length recovery has been noticed after applying index matching gel at the end face of the fiber. However, the beam profile gets distorted which is due to uneven surface of the gel at the end face. Therefore, in case of applications where shape of the beam is important, this technique may not be effective enough.

### 4.4. Polishing of fiber end

Polishing of fiber end was found very effective in terms of elimination of back reflections, recovery of coherence length, efficient coupling [16, 17] and improvement in beam quality. Polishing can be carried out using a grinding wheel or machines that are commercially available on the market [18]. These machines are well equipped with gadgets to hold the fiber firmly over the grinding wheel, hence to achieve desired results. However, in absence of professional polishing machines a need arises to develop such a system for the purpose which should be capable of polishing the fiber end at a low cost.

## 5. A METHOD FOR POLISHING FIBER ENDS

Small diameter fibers are difficult to polish due to its ductility. Therefore, there arose a need to develop a technique to handle the fiber so that grinding wheel could polish it effectively. For this purpose, a thick walled capillary tube having outer diameter of 5 mm was used. The capillary tube was mounted into a plastic tablet as shown in Fig. 2.

The outer diameter of tablet was 25 mm. Mounting of plastic tablet helped to facilitate the holding and keeping the bottom surface of tablet as flat as possible. The optical fiber was then dropped into the capillary space of the tube such that the fiber end and bottom face of capillary tablet assembly were flushed to each other. Now there was a need to solid fix the fiber inside the capillary gap.

For this purpose, sealing wax was selected due to its low melting point and quick solidifying state. A small heap of powdered sealing wax was made available on a plane glass surface. Now the bottom end of capillary tablet assembly was heated up using a gas burner as shown in Fig. 3. Once the assembly including the fiber had achieved sufficient temperature, it was pressed hard against the powdered wax. Wax melted due to temperature and rose into the capillary due to capillary action. Capillary action is explained as the ability of a molten material to flow in reasonably narrow spaces without any assistance from external forces such as gravity [12]. As the wax was introduced to the assembly, its temperature fell down hence solidifying the wax to pack the optical fiber tightly in the assembly as shown in Fig. 3.

After that the bottom face of the assembly was polished using grinding wheel which was fitted with a grit paper of suitable grade. Time to time inspection was carried out, as shown in Fig. 4, during the polishing process with the help of microscope. The process of polishing continued until required level of polished surface was received.

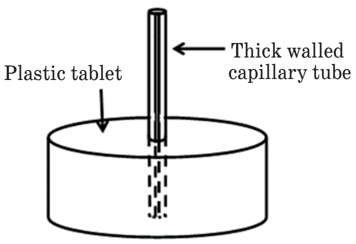


**Fig. 2.** Capillary tube and plastic tablet assembly.

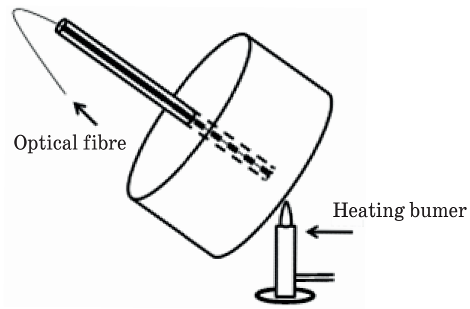


**Fig. 3.** Heating the assembly after inserting optical fiber in the capillary.

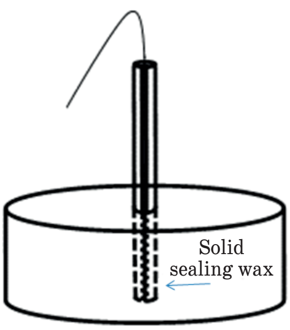


**Fig. 4.** Optical fiber packed in the assembly.

## 6. RESULTS

Coherent length of the laser light launched into single-mode fiber was measured, before and after polishing, using Michelson interferometer as shown in Fig. 5. An improvement in the coherent length was gained from few centimeters to 2 meters by observing the lasting of interference pattern on the screen (S).

Quality of laser beam was later on inspected after polishing, using the set up as shown in Fig. 6.

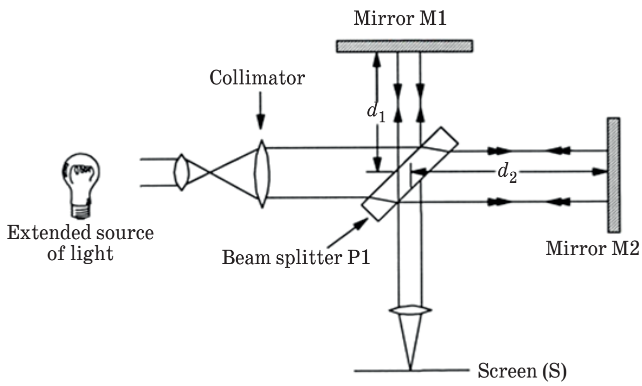


**Fig. 5.** Basic setup of Michelson interferometer [19].

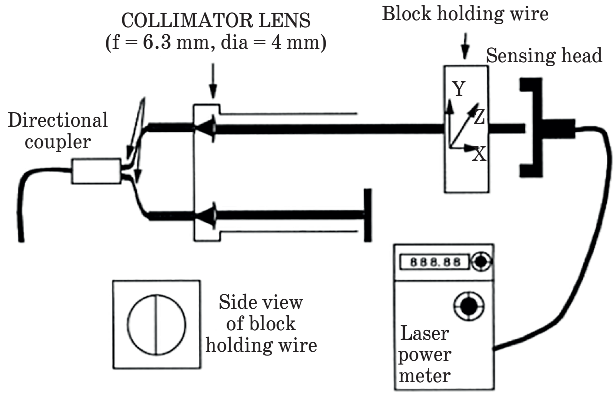


**Fig. 6.** Arrangement for checking beam profile.

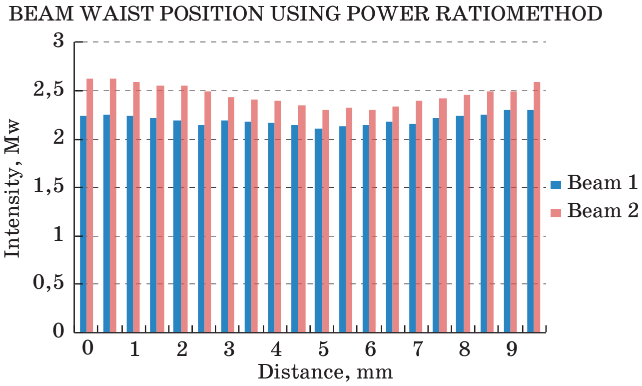


**Fig. 7.** Beam waist presentation after polishing the end face.

In this setup a metal wire was used for shining through the laser beam. The wire was fitted onto a metal block. The metal block was mounted onto a mm traverse to facilitate its sweep across the beam. The traverse was moved in to steps of 0.5 mm to record the power of the beam with respect to each step. Improvement in two beam shapes in terms of Gaussian distribution was measured and data are presented in Fig. 7. The plot clearly presents Gaussian profile of the beam after polishing the end face.

## 7. CONCLUSIONS

An enormous improvement in coherence length and Gaussian light distribution in the laser beam was observed. Nevertheless, the results were achieved by adopting a new approach to hold optical fiber as compared to professional holders available on the market. The system developed here has been cheap, reliable and bears repeatability.

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