Interferometric inspection of optical fiber end faces

By David Robinson, CEO, Arden Photonics Ltd

Introduction

There are many situations where detailed information about the quality of an optical fiber end face is useful or important. For connectorized fiber, inspection microscopes and interferometers are widely available and can provide useful information such as assessment of scratches and parameters such as Radius of Curvature and Apex Offset. The use of interferometry in specialty optical fiber applications, however, is less well established. Interferometric inspection of optical fiber end faces is quick and simple, yet it can yield valuable information to the manufacturer in the fields of medical, aerospace and industrial optics. Interferometers can provide manufacturers of a variety of optical fiber products such as active components, fiber arrays, bundles, cleavers and fiber lasers with essential process control information which can improve productivity and ensure quality.

Fiber end face interferometry

The optical arrangement often used for fiber end-face measurements is that of a Michelson interferometer, which is shown schematically in Figure 1.

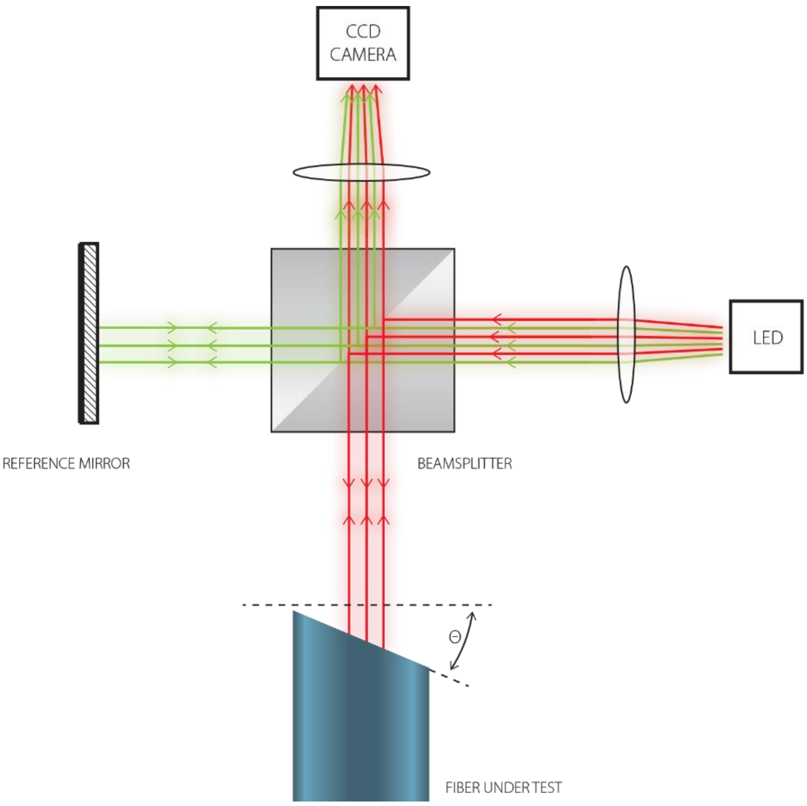


Figure 1 – optical layout of a typical fiber end-face interferometer

In this arrangement, light from a source, typically an LED, is divided using a beamsplitter. One half of the beam is directed onto the end face of the fiber; the other is directed onto a reference optical flat which is positioned at the same distance from the beamsplitter as the fiber under test. Light reflected off these two surfaces is then recombined by the beamsplitter and imaged onto a sensor such as a CCD camera.

Scientists in the 20th century showed that light can act as if it is either a particle or a wave, depending on the circumstances. In an interferometer, light clearly shows its wave-like nature. Difference in the path length of the light ray between the object and the reference flat cause phase differences in the two waveforms. When the two waves re-combine in the beamsplitter, they interfere either constructively or destructively depending on the relative phases as shown in Figure 2. This leads to the characteristic fringe pattern of black and white bands which is used to assess end angle.

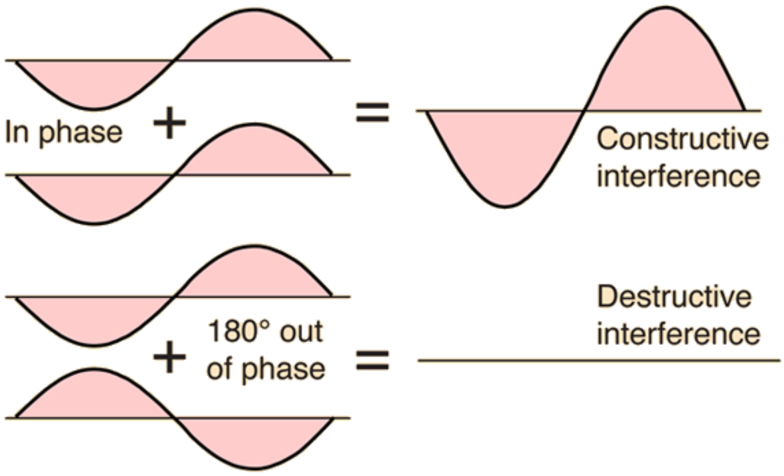


Figure 2 – constructive and destructive interference

Characteristics of a fiber end face interferometer

Fiber end face interferometers should have several characteristics which make them suitable for this kind of work.

- **High magnification** is required to enable the interferometer to examine fibers down to 80µm in diameter. This should be allied with high resolution to see dirt and scratches.
- **Non-contact** - It is also important that the fiber tip is not in contact with the optics to ensure that the sample itself and the optics inside do not become contaminated. Therefore, a working distance of a few millimetres is important.
- **Fiber holders** - Ensuring the position of the fiber tip is well controlled is critically important when making accurate end-angle measurements so specially designed fiber holders are required for each fiber size.

A separate “inspect” mode is often provided in order to see surface defects such as dirt. On a cleaved end face other defects which the manufacturer might look for are cleaver blade impact damage, hackle, dirt. Polished fibers may exhibit chips and scratches. With high quality optics and convenient fiber handling these defects can be screened out effectively, but the real benefit of the interferometer is to give information about the flatness (planarity) of the fiber end, and its end angle.

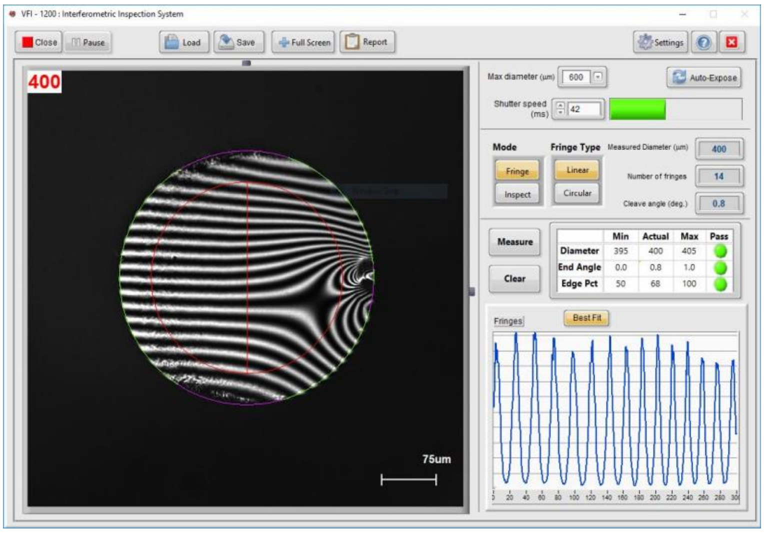


Figure 5 – 400 µm diameter fiber with end angle of 0.8 °

End angle calculation

A fringe pattern may be thought of as a contour map of the surface of the fiber end. Like a contour map, closely spaced fringes represent a steep gradient and widely spaced fringes represent a gentle gradient. The fringe spacing is determined by the wavelength of light used in the measurement. So the cleave angle can be calculated as follows

$$tan\theta = N\lambda/2D$$

where the N is the number of fringes over a distance D, and λ is the centre wavelength of the source.

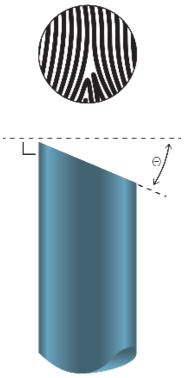


Figure 3 – optical fiber with a typical fringe pattern

For example, for an LED source with a wavelength of 587 nm, and a fiber of 125 µm in diameter, 5 fringes corresponds to

$$Arctan\left(\frac{5 \times 0.587}{2 \times 125}\right) = 0.67°$$

Of course, there is no need to use the full fiber diameter for measurement. Often it is preferable to use only a section of the surface. This can help to avoid distortions caused by blade impact in precision mechanical cleaving or rounding of the fiber edge which can occur in laser cleaving.

Definitions and standards

Measuring cleave angle is referred to in the following international standards: Bellcore Technical Reference TR-NWT-000264.

It is worth noting that the end angle, θ, is defined in standards as the angle between a plane drawn at 90° to the optical axis of the fiber and a plane drawn through end face of the fiber itself. This definition assumes that the cleave, whilst having an end angle θ from the fiber cross section, is planar.

In this definition, a fringe is defined as the one black or white line on the interferogram. Sometimes in interferometry, black and white fringes are counted separately, a black and white fringe being known as a fringe pair. So in the example above one fringe corresponds to about 0.13° and the resolution of the system is better than 1 fringe so the measurement accuracy using this method can be taken to be about 0.1°.

Planarity

Although the definition of end angle assumes that the cleaved or polished end is planar in reality this is never the case. The planarity of the fiber end face can be judged by the straightness of the fringes. A fiber which shows predominantly straight fringes can be regarded as planar whereas a fiber which has curved fringes is non-planar.

Generally, cleaves performed using a well-adjusted precision cleaver are planar to a fraction of a degree over the majority of the surface so if the angle on the fiber end face is less than around 0.4 degrees the fringes will appear curved and so the end angle of the fiber is of the same order as the planarity of the surface. Cleaved end faces made with poorly set up cleaves or with a deliberately induced end angle of 8° can be far from planar. The accuracy of the end angle measurement will be reduced as a result.

Polished fibers have a different characteristic. Here the fringes tend to be round indicating that the fiber tip is domed, more like a connector.

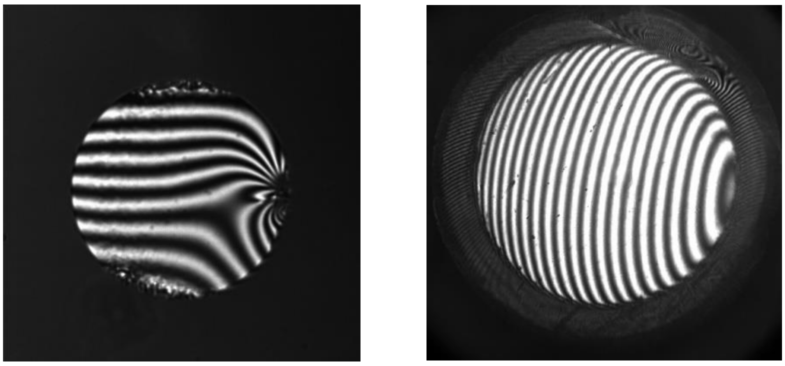
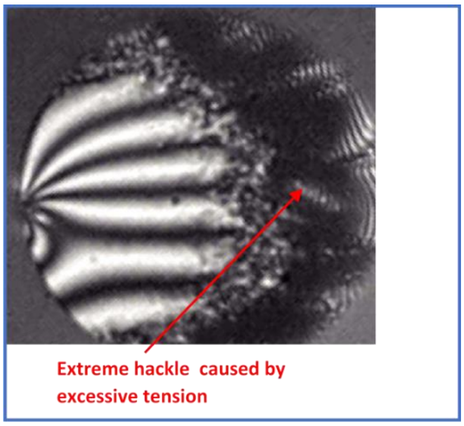
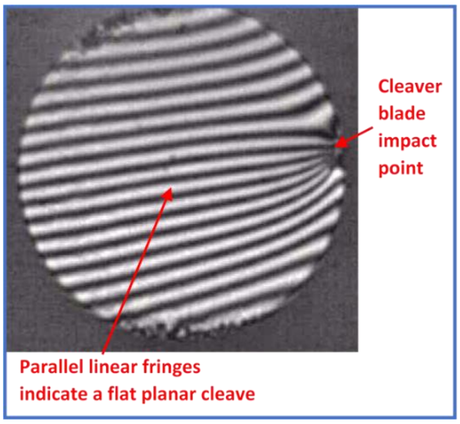
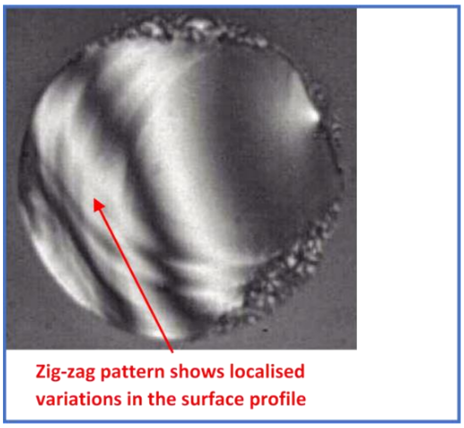


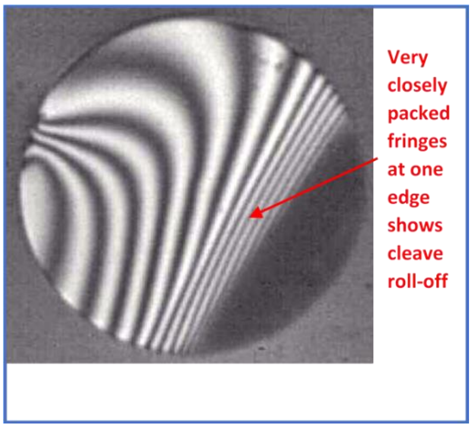
Figure 4 – Interferogram of a precision cleaved fiber (left) and a polished fiber (right)

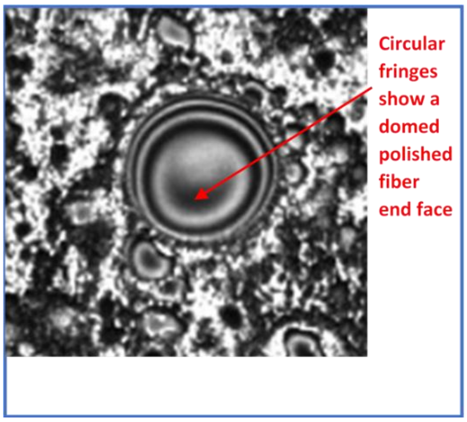
What can be spotted during interferometric inspection?











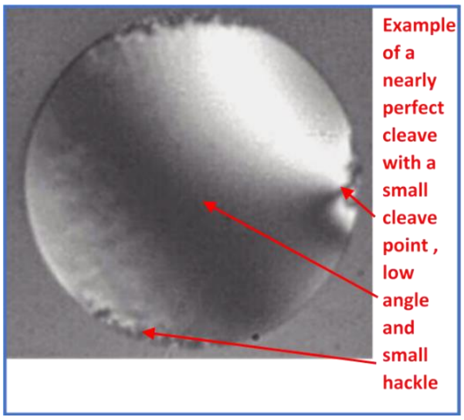


Figure 6 shows a typical 125µm fiber cleaved using the type of cleaver used in factories throughout the world. These 2 images taken together can yield a lot of information for the operator.

- Average fringe count is 5 fringes so the cleave angle across the middle of the fiber is about 0.6 °
- The inspect image is revealing that the cleaver blade has penetrated about 10µm into the fiber. This is backed up by the high fringe density round the blade impact point. This may indicate that the blade height or alignment is not optimal.

- The "hackle" zone in Inspect mode is quite pronounced. This means that the cleaver is of the type which applies tension to the fiber during the cleaving process, and that this tension setting is high. The tension setting in the cleaver could be reduced without adversely affecting the cleave angle.
- Particles of dust can be seen in the inspect view. If the fiber is to be fusion spliced, these particles will burn off during splicing but if some other processing is required the fiber may need to be cleaned before proceeding.

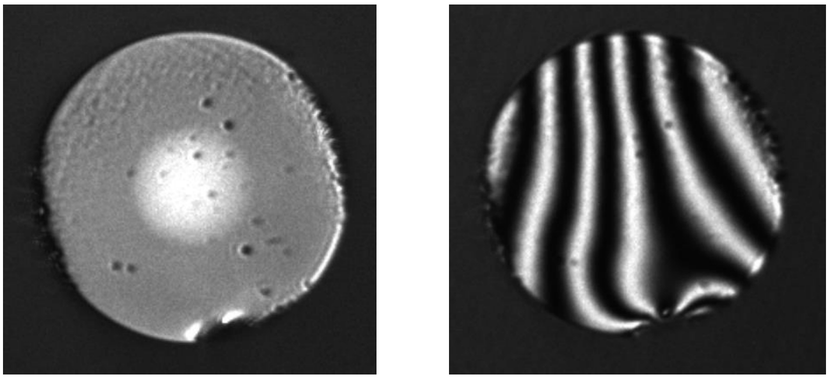
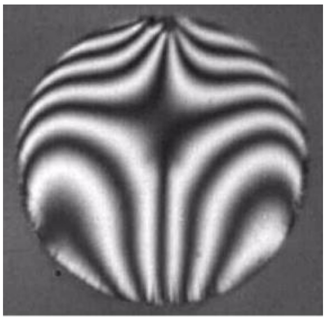


Figure 6 – images of a typical 125µm diameter cleaved fiber

Applications

As well as giving assessments of standard fibers, an interferometer can be useful in checking other structures.

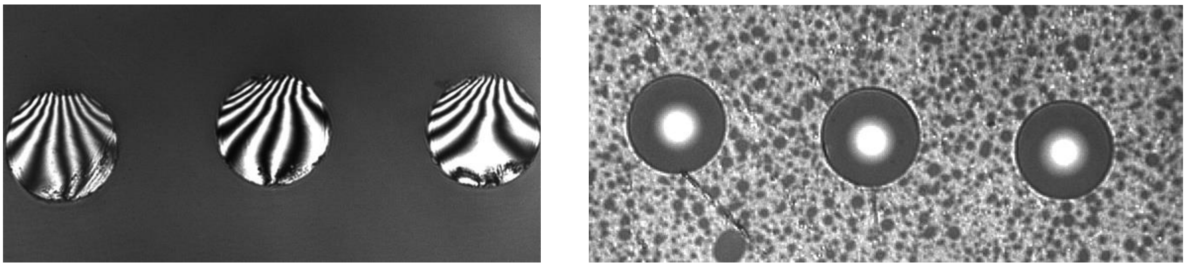
1) Angled fiber cleaves -



The variability of end angle is greater for cleaves with a deliberately induced end angle. In applications where reduced back-reflection is important, more frequent measurement of end angle can be required to ensure consistency.

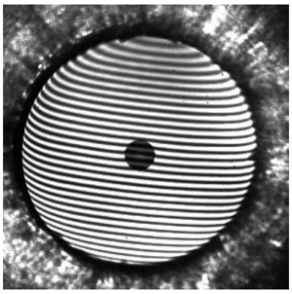
Angled cleaves can be measured directly if the interferometer has sufficient fringe resolution and contrast. Alternatively, the fiber itself may be tilted using an angled holder. This reduces fringe density which gives better information about the planarity of the cleave but it does involve a more complicated set-up because the fiber may need to be rotated on its axis.

2) Ribbon structures



Interferogram of a ribbon cleave (image on the left) and inspect view of fibers in a multi-way ferrule (image on the right).

3) Ferrules



Interferometry can also be a powerful tool for inspecting fibers inside ferrules. Here is an image of a flat polished 1.25mm ferrule with a 125µm hole in the middle.

Conclusion

Interferometry is a powerful tool for process development and quality control in optical fiber manufacturing environments. It can give important information about factors which can affect splice loss, back reflection, component reliability, light propagation characteristics and scattering. Using industry standard holders, the process can easily be integrated into a manufacturing workflow incorporating cleaving, polishing, splicing and bonding. Convenient software can allow go/no-go testing and data storage, which means the whole measurement can be completed in seconds.

Arden Photonics Ltd
Royston House
267 Cranmore Blvd
Solihull
B90 4QT
UK

+44 121 733 7721

Arden Photonics, LLC
4500 140th Avenue North
Suite 101
Clearwater
FL 33762
USA

+1 727-478-2651

www.ardenphotonics.com

enquiries@ardenphotonics.com