Interferometric Measurement of Fiber Optic Parameters

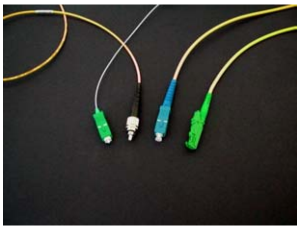
Forward

The transparency of optical fibre as a transmission medium allows it to carry a variety of signal types, including voice, data, RF and video protocols. Networks are increasingly required to carry a combination of these over the same fibre.

Each application has different bandwidth requirements, and as the use of the Internet develops, the demand for the bandwidth, both on public and private networks (LANs) is increasing. Internet traffic is currently doubling every year. There is a convergence of technologies, as this broadband capability has become the priority for communication networks at the 'access point', where the public network interfaces with the private networks (LANs).

The public networks have traditionally used singlemode fibres requiring the highest level of precision technology. Bandwidth increases have been achieved by increasing transmission speeds and the utilization of Dense Wavelength Division Multiplexing (DWDM) that is operating more and more wavelengths down the same fibre. This has resulted in manufacturers focusing on every passive component and its contribution to link attenuation, performance, reliability and security.

Key parameters are the measurement of insertion loss and return loss (back reflections) for every optical connection in the link. In an attempt to control and improve these parameters connector manufacturers have focused on three areas. a) The improvement of component tolerances (improved alignment), b) the improvement of visual inspection (screening of defects and contamination) and c) the characterisation of end-face symmetry (optimising the interoperability between manufacturers and the performance life of the connection). These are critical not just to achieve the insertion loss and return loss parameters in production but to assure the performance of the connector during all the environmental and mechanical extremes that will arise in use.



Permitted by shorter link distances, the private networks have traditionally used lower cost multimode fibres and components. Less attention has been paid to environmental extremes as the traditional connectivity is usually in a controlled environment. The requirements for low back reflections over the life of the network have made connector ferrule end face symmetry measurements a necessity in the singlemode Telecom market. Whilst the same level of performance is not required for multimode systems the same parameters are now being adopted by specifiers and standards groups working on critical networks and systems in the private network markets, such that life time and environmental performance can be guaranteed.

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Physical requirements on optical connector end faces

An optical connector is generally made of a ferrule surrounded by a housing. The ferrule can take the shape of a cylinder, drilled with a small bore at its center in which the fiber is glued. The end face of the ferrule is then polished, usually in a spherical manner (see diagram 1).

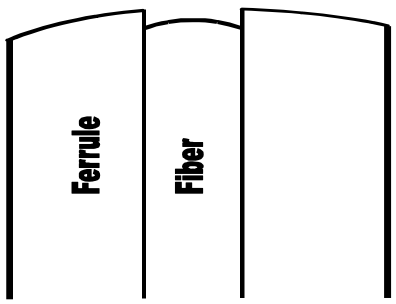

Diagram 1: Side view of a cylindrical ferrule + fiber

In long haul, high bandwidth, applications, an optical connector must be able to perfectly interface two optical fibers together in order to have the best optical continuity as possible.

Ideally, in the case of two mated single fiber connectors with a cylindrical ferrule, both ferrules and fibers come in contact and deform to a certain extent in order to form a neat interface over a central portion of the ferrule with no air gap. In such case, the ferrule will hold a large portion of the pressure applied on the surfaces and ensure that the fibers are not over-strained, which would yield reduced optical performances and early ageing. Having no air gap around the fiber-core region is essential in order to avoid large index of refraction changes along the optical path, hence avoiding a large amount of optical reflection into the source and link attenuation.

In order to ensure such working conditions, the symmetry of polishing of the ferrules end faces must meet very tight criteria. Diagram 2 shows the critical symmetry parameters that must be controlled in the production environment and diagram 3 shows the typical symmetry defects and their effects on the optical performances on the connection.
Standards and specifications have been put in place in order to insure interoperability between various types and sources of optical patch cords. Table 1 and graph 1 show typical criteria on the symmetry as described in such standards.

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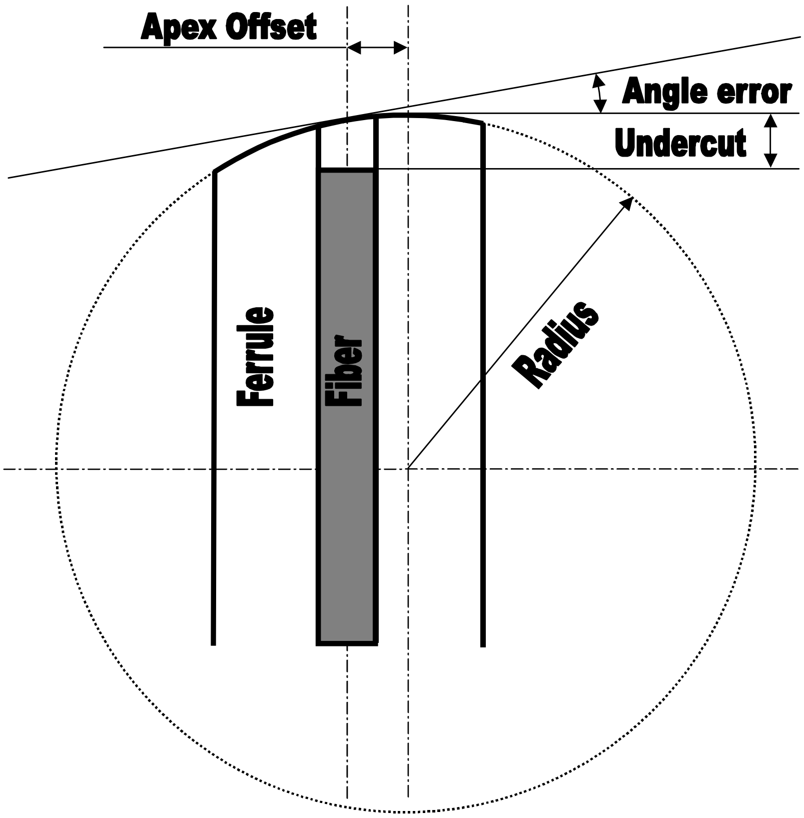

Diagram 2: Critical symmetry parameters of an optical connector end face

Note in graph 1 that the maximum allowed undercut is a function of the radius of polishing of the end face. Future standards will, logically enough, also include the apex-offset in addition to the radius as a parameter for the allowance of the maximum undercut.

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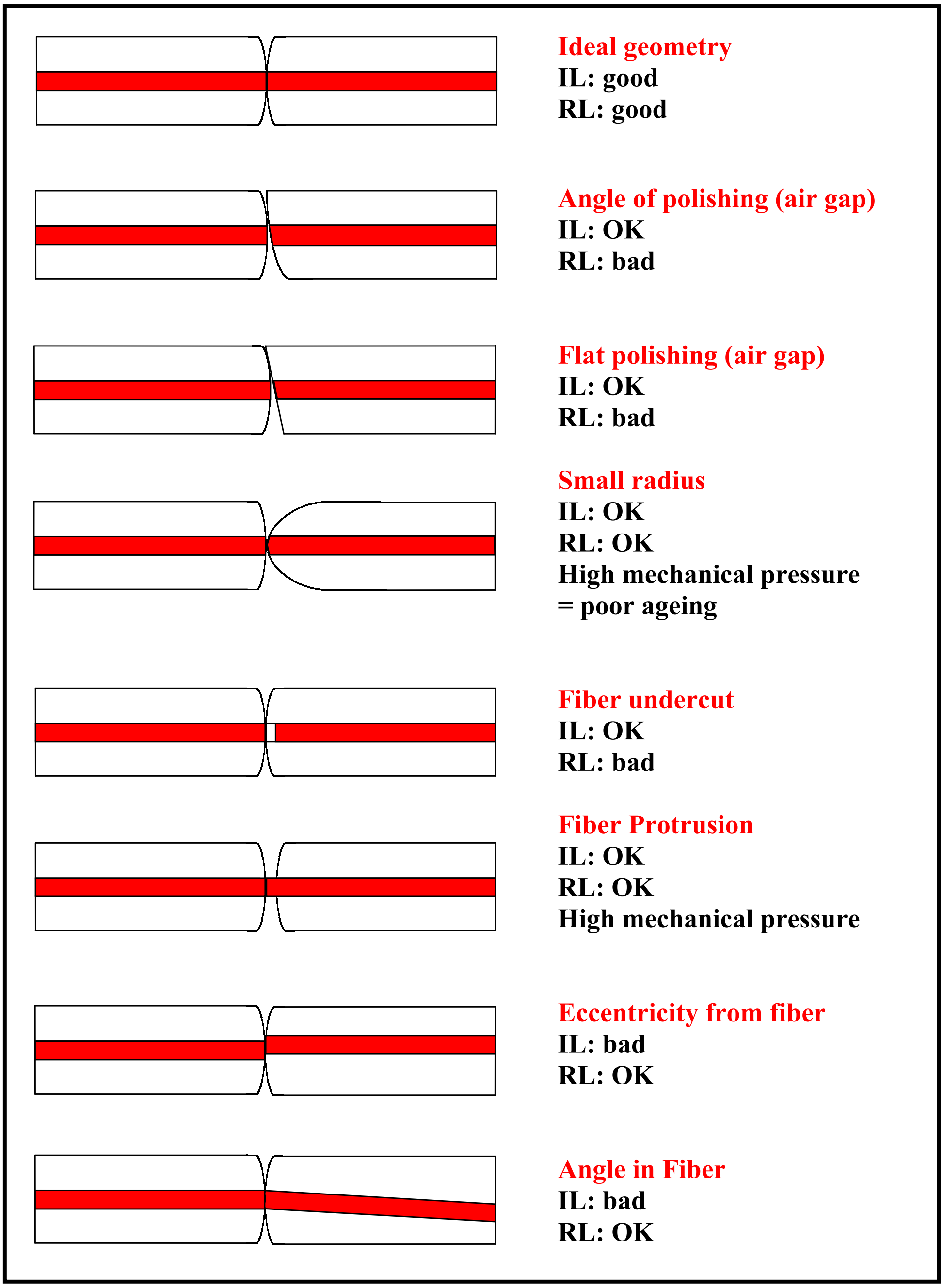

Diagram 3: Typical symmetry defects of polished ferrule end faces

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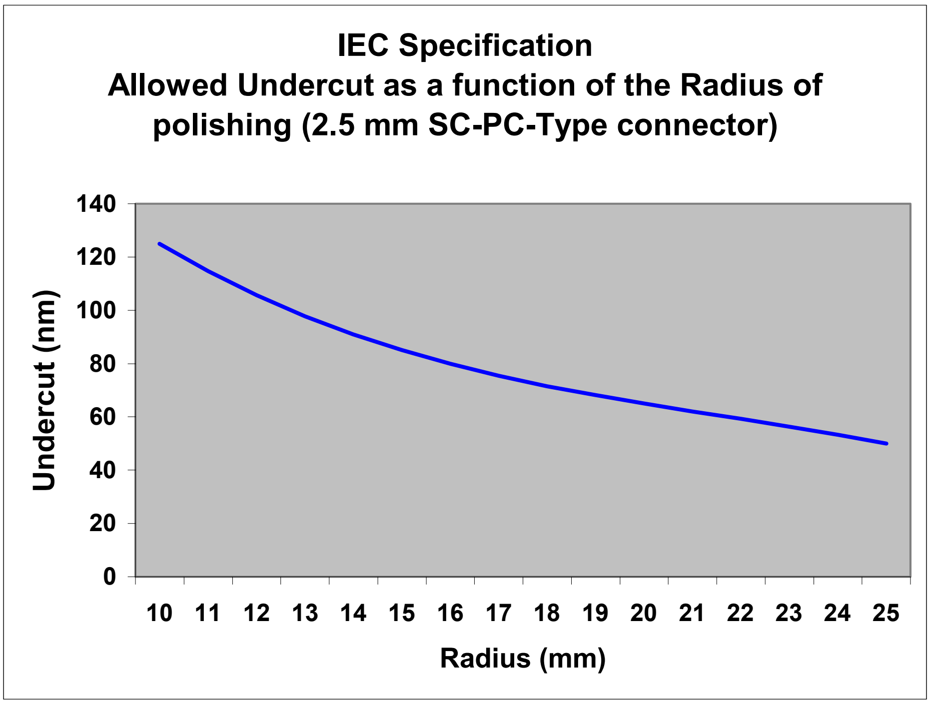
	Radius (mm)		Fiber Height (nm)		Apex-Offset (µm)	
Allowed range	min	max	min	max	min	max
PC polishing	10	25	equation	100	0	50
APC polishing	5	12	-100	100	0	50

Table 1: typical required specifications for the end face geometry (IEC spec for an SC-type connector)



Graph 1: IEC Equation for the allowed maximum undercut of a fiber of an SC-PC connector type. The allowed undercut is a function of the radius of polishing.

The measurement area over the ferrule end face is typically of 250µm and Z-axis sub micron accuracy is necessary in order to measure the fiber height (undercut) parameter.
The surface to be measured is optically polished and does not usually have abrupt height steps.
For this application, optical monochromatic interferometry in combination with phase shifting is ideally suited.

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Optical monochromatic interferometry, back to basics

Interferometry is a non-contact optical technique whereby the topography of a surface such as a ferrule end-face can be measured with great precision (typically a few nanometers in Z).

Interferometry uses the wave property of light. In a typical interferometer (see Diagram 4), an imaging system superimposes two images of distinct objects onto a camera CCD captor. One image would be of a reference flat surface (a mirror) and the second one of the sample to be measured. Under certain conditions, the two superimposed images (wave fronts) can be made to interfere, yielding the well known « fringe pattern », constructive and destructive interferences that is. See image 1 for an image of an end face with interference fringes.

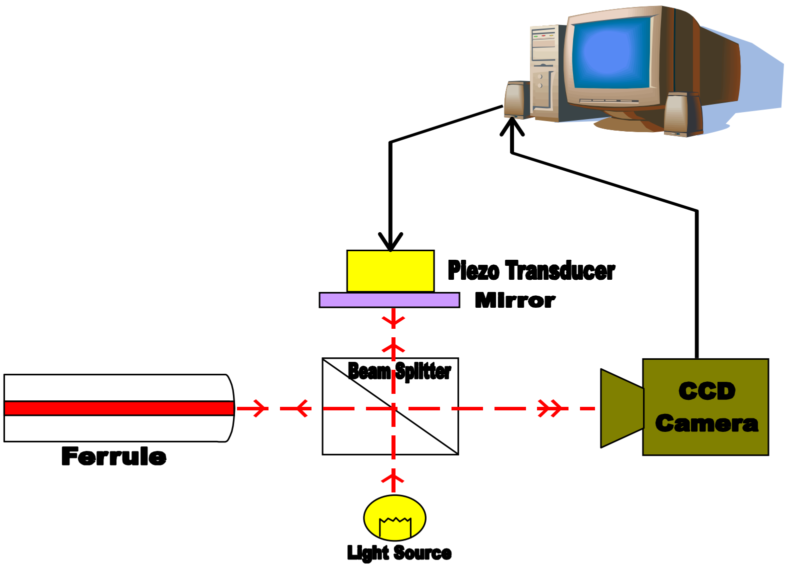

Diagram 4: Optical interferometer setup, « Michelson type »

Simply looking at the fringe patterns in image 1 gives us some insights into the real shape of the end face. Interference fringes can be thought as being iso-height lines, similar to the ones on a geographical map. The vertical height-difference separating two fringes is exactly 1/2 of the illumination source wavelength, 0.33µm in this case. The circular shape of the fringes indicates a spherical type of shape, the center of the fringes being the highest point of the end face (the Apex). Ideally, the apex would be centered on the fiber central-axis. If not centered, then the offset is called the Apex-Offset. The number of fringes then gives us an indication on the radius of polishing and a step in the fringes at the ferrule-fiber interface is an indication of a difference in height between the fiber and the ferrule.

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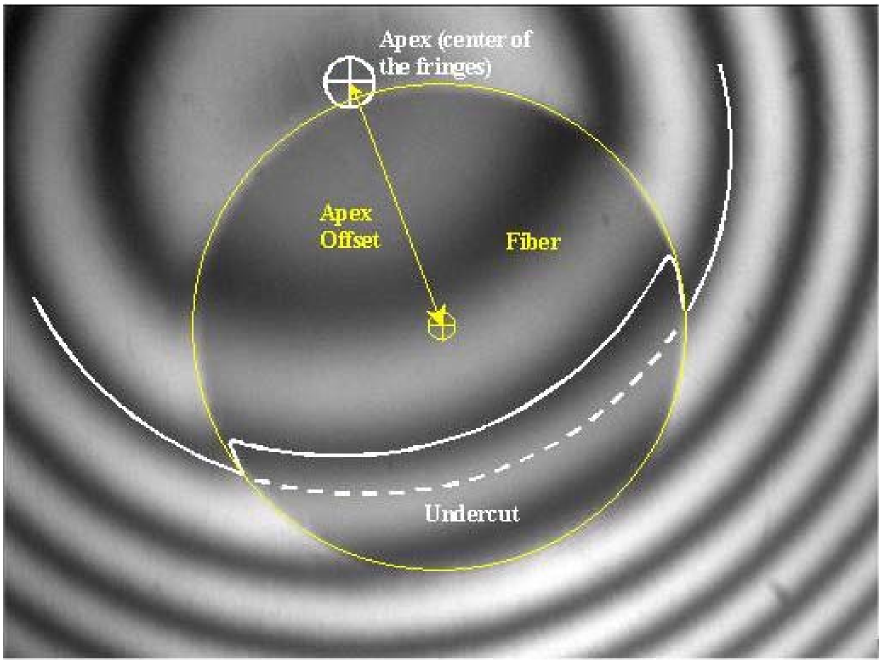

Image 2: Interference fringes on the surface of a ferrule end-face. The central circular part highlighted in yellow is a 125µm fiber.

Quantitative and automated analysis of the surface topography is possible through the use of the well-known « phase-shifting » technique.

Phase-shifting technique

The phase shifting technique is based on the idea that the shape of the surface to be measured is linked to the phase difference at each pixel of the image between the two interfering wave fronts. However, our eyes and other detectors cannot detect phase, only intensity. Interference however, converts phase data, which we cannot see, to intensity information, which we are able to quantitatively detect. At each pixel of the image, the intensity of the interference pattern is a function of three *a priori* unknown parameters, namely amplitude, contrast and phase difference between the two wave fronts (the actual parameter we want to measure).
By sequentially introducing a known phase-shift between the two interfering wave fronts and by recording the resulting image each time (at least three times), one can calculate the three unknown parameters, especially the phase-difference value for each pixel, yielding the so-called « phase-map » as shown in image 3.
A fundamental limit we then run into is the fact that the phase value for each pixel is not single-valued, due to the cyclic nature of waves. Our calculated phases are in fact modulo 2π valued.
One way around this problem is to assume that the surface under measurement is fairly continuous and that physical height steps between neighboring pixels of the phase-map do not

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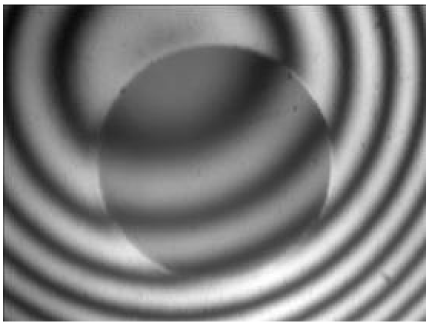
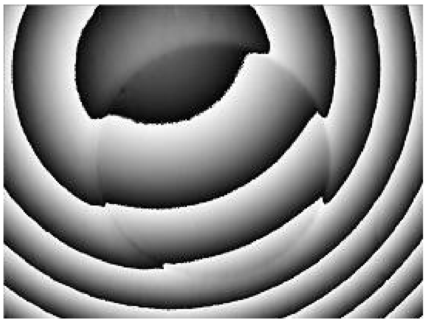
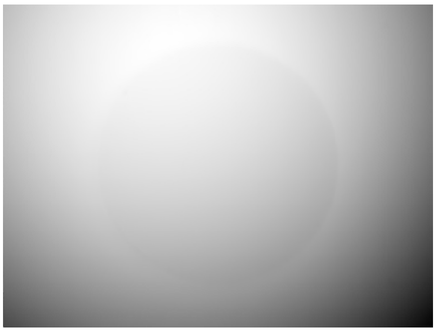
exceed one half of a fringe. This fundamental limitation of monochromatic interferometry reduces the application range of this technique to smooth and continuous surfaces.
Having this limitation in mind, we can remove the phase jumps in a procedure called « phase-unwrapping » in order to get a continuous height map, also called the « unwrapped image ».



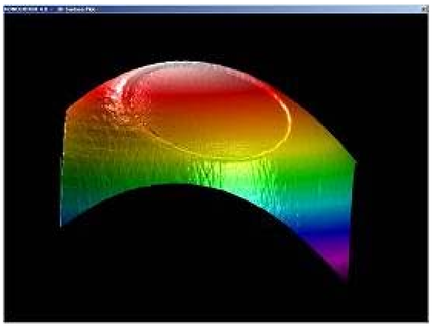
Step1. Contour fringes of ferrule end-face



Step 2. Phase image



Step 3. Unwrapped image



Step 4. 3D profile of ferrule end-face

Image 3: Steps of the phase shifting technique. The 3D representation at step 4 is simply a plot of the intensity level of the unwrapped image

Calculating and displaying the surface topography of a sample using the phase shifting technique only take a few seconds, thanks to today's available computing power.

Once the surface shape is calculated numerical analysis enables a fast and precise calculation and analysis of the surface symmetry parameters (i.e. Radius, Apex-offset, Undercut, etc.).

Some measurement examples of ferrule end faces are shown below:

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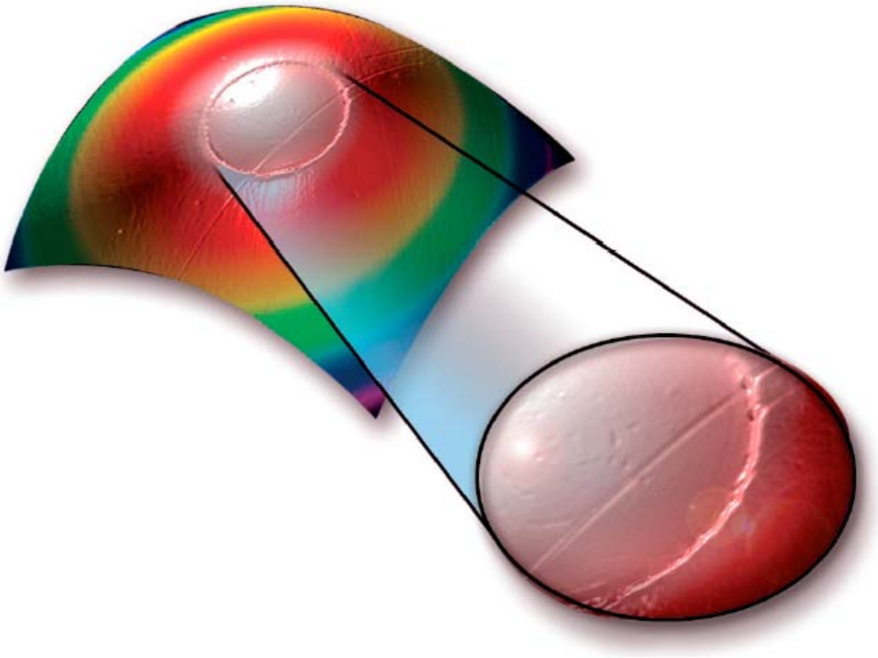

Image 4: False color 3D representation of a measured ferrule end face with the *Koncentrik* system from Data-Pixel. The fiber, located on the central part of the plot, shows a clear undercut as well as a scratch, as enlarged in the zoomed section. Epoxy-ring bubbles. Undercut amount in this case is 140nm.

Parameters' values can then automatically be compared to pre-set PASS/FAIL criteria as defined in the standards and automated measurement report generation summarizes results. Image 5 shows such a task.

This article presented the optical monochromatic interferometry as a powerful tool for quality assurance in the production of optical patch cords. It enables full, fast and automated characterisation of the ferrule optical endface with great precision and ease of use.

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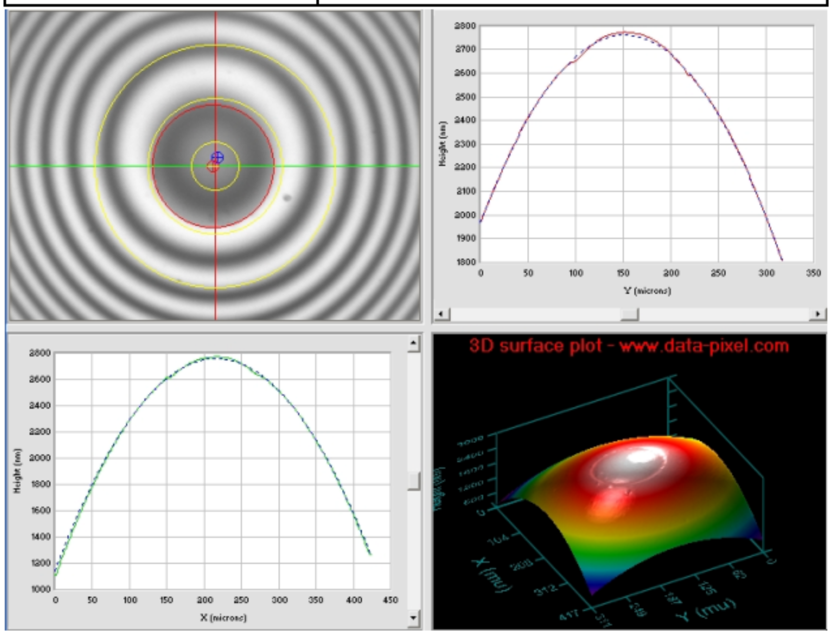
Sample ID: Sample-348		PASS
Sample Type:	PC	
Measurement Time & Date:	11h58m05s, Sep 23, 03	
Fitting Regions:	D=250um; E=140um; F=50um;	

Measurement Parameter	PASS/FAIL Settings Minimum	PASS/FAIL Settings Maximum	Measurement Result		Passed or Failed
Ferrule Radius of Curvature	10,00	25,00	14,43	mm	PASS
Fiber Radius of Curvature	0,00	100,00	12,73	mm	PASS
Fiber Height (Spherical Fit)	-88,3	100,0	10,7	nm	PASS
Fiber Height (Planar Fit)	0,0	300,0	162,4	nm	PASS
Apex Offset	0,0	50,0	9,6	µm	PASS
Apex Bearing	0,0	360,0	34,5	deg.	PASS
Angle Error	-0,600	0,600	0,038	deg.	PASS
Key Error	n/a	n/a	n/a	deg.	PASS
Fiber Roughness (Sq)	0	50	2	nm	PASS
Ferrule Roughness (Sq)	0	50	4	nm	PASS
Ferrule Bore Diameter	123	130	125,5	µm	PASS
Comments					



Sample ID: Sample-348	
PASS	11h58m05s, Sep 23, 03

	1310nm	1550nm
IL	n/a	n/a
RL	n/a	n/a

Image 5: Automatically generated EXCEL report of the measurement of a ferrule end face. PASS / FAIL criteria are based on international standards or can be customized to end-user requirements.

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