Polishing Dependence of an Optical Fiber Connector's Damage Layer

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Abstract: We present a method for measuring the thickness (in μm) and index of refraction of the high index damage layer at the end of an optical connector by using a standard dual wavelength back reflection meter. Using this method, we have systematically studied the extent of the resulting damage layer from various final polish process steps by varying polishing film types, pressures, times, etc. Such information can enable connector manufacturers to achieve consistent "Hyper PC" return loss performance from non angled connectors as desired by some end users.

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1. Introduction

In physical contact (PC) optical fiber connectors, the high index damage layer is the area on the connector's end face where the polishing process has compressed the glass giving a localized index of refraction increase. This damage layer [1] is one of the main intrinsic parameters of an optical fiber connector that ultimately limits the connector's ability to achieve the lowest reflectance (i.e., highest return loss) possible from non-angled fiber optic connectors. It is a desire to have high return losses from non-angled connectors because communication service providers want the fiber optic plant they build to be capable of carrying any type of signaling their customers may ultimately desire -- including analog CATV signaling, which is notoriously sensitive to back reflections in the cable span. However, the service providers may also desire that the new plant they build out to be backward compatible with their installed base of non-angled connectors. This is because mixed angled (i.e., APC) and non-angled (PC) connectors plant is potentially vulnerable to craft error, as mating an angled with a non-angled connector will damage both connector types Consequently, it is a requirement of Telcordia GR-326 [2] to have Return Losses of non-angled connectors to be consistently in excess of 55dB (with an objective as low as ~60 dB) and connector suppliers are constantly trying to find ways to consistently manufacture such so-called "Hyper PC" performance from non angled connectors [3].

We present a method for measuring the high index layer using a standard dual wavelength back reflection meter. Using this method, we have systematically studied the extent of the resulting damage layer from various final polish process steps by varying polishing film types, pressures, times, etc. By measuring the reflectance or back reflection (in dB) at different wavelengths, we calculate the thickness (in μm) and index of refraction of the damage layer. We then correlate these with the various polishing steps. Finally, we provide guidance to the connector industry on how to best achieve consistent "Hyper PC" performance as desired by some end users.

2. Measurement Method

The back reflection of a fiber optic connector junction has three main contributors:

1. Surface defects (scratches, pits)
2. Presence of an air gap between the two fibers
3. High index damage layer on the surface of the connectors

Surface defects are measured by optical inspection (microscopy), and the air gap is eliminated by assuring proper geometry to enable physical contact between the connectors (interferometry). Currently there is no non-destructive test method available to independently measure the thickness and refractive index of the high index damage layer. While a similar method has been presented [4], that method will not minimize the RL contribution of surface defects.

Note that during an optical fiber connector's terminating process, the end face of the connector is prepared by a series of polishing steps utilizing finer and finer grit sized polishing films. In a stable polishing process, each step will remove the damage of the previous, coarser step, and leave its own smaller damage layer. Here we focus on the final damage layer induced by the final film.

3. Test Procedure

A Sagitta Gemini-Cx integrated polishing, cleaning, and inspection processing cell was used to prepare the all the fiber optic connectors under test. This machine is used because it is one of the few commercially available fiber optic connector manufacturing tools that enables a user to conveniently vary the polishing pressure, time, and materials.

In order to create our test samples, a series of fiber optic patch cords (jumpers) are prepared as follows:

- Six LC-LC jumpers are polished using a standard polishing process. The process is chosen to produce connector geometries that will guarantee physical contact of the ferrules. Both ends of the jumper are polished normally except for the final step.
- End 1 of each jumper is polished using a standard silica oxide abrasive (Mipox Final Finish Film SO-5X). (See Figure 1)
- End 2 of the jumper cord is finished with one of the test polishing steps as indicated in Table 1 below. In all cases, sufficient time was used to assure the previous damage layer was completely removed.

After the jumpers have been prepared, each of the connectors under test (CUT) are measured with a dual wavelength JDSU RM-3 back reflection meter (aka reflectometer) with a standard APC/UPC hybrid jumper as supplied by the manufacturer (See Figure 1). The CUT is placed in index matching gel which acts as a beam dump. The back reflection (BR) of the CUT is measured at 1310nm and 1550nm. The back reflection contribution of the rest of the system is measured by mandrel wrapping the jumper to eliminate the contribution of the CUT and again measuring at 1310nm and 1550nm. The mandrel wrapped and unwrapped back reflection readings are subtracted, thus isolating only the back reflection contribution from the CUT within the index matching material.

The index matching material is chosen to match the index of the fiber core. Since the fluid is in contact with the fiber, there is no air gap. Also, since the index of the fluid is very close to that of the high index layer, the back reflection contribution of any surface defects is minimized. The beam dump is constructed so that no transmitted power is reflected back into the CUT.

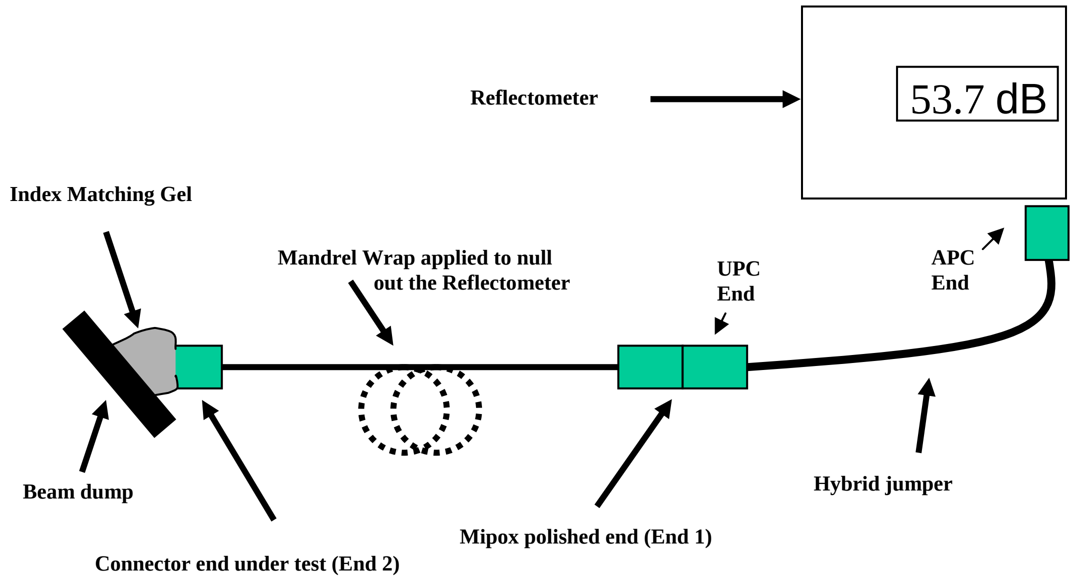

Fig. 1. Test Setup

4. Interpretation of Measurement Results:

We assume the high index damage layer is a single homogeneous layer on the fiber end face, as in Kanayama, et al. [4]. In that case, the BR of an optical fiber with a high index layer on the surface and the surface mated to a beam dump with a refractive index equal to that of the core is given by the following equation:

$$BR = -10Log(4n_g^2 n_L^2 + \left[n_g n_L - n_L^2\right]\sin^2\left(\frac{2\pi n_g}{\lambda} h\right) \quad (1)$$

Where

n_g = refractive index of the fiber core
n_L = refractive index of the damage layer
λ = incident wavelength
h = width of the high index damage layer

Measurement of the back reflection at two wavelengths (BR_{1310} and BR_{1550}) yields two equations and two unknowns (n_L, h). The two equations can then be solved numerically to obtain both the index and thickness of the damage layer.

5. Results

Results for five different final polishing materials are summarized in Table 1. Each of the measured and calculated data points represent the average of 6 jumpers.

Table 1. Test Polishing Parameters and Results

Polishing Parameters		Measured		Calculated	
Final film	**Force/connector (grams)**	**BR_{1310}**	**BR_{1550}**	**n_L**	***h***
1 µm diamond	80	35.9	37.2	1.509	0.162
0.1 µm diamond	30	45.5	46.8	1.483	0.143
0.1 µm diamond	80	43.0	44.3	1.492	0.120
0.1 µm diamond	160	43.2	44.3	1.485	0.172
0.1 µm diamond	480	45.0	46.1	1.479	0.218
1 µm alumina	30	55.9	54.5	1.471	0.431
1 µm alumina	80	48.7	49.5	1.476	0.212
1 µm alumina	160	46.4	47.2	1.494	0.207
1 µm alumina	480	39.0	40.6	1.661	0.042
0.3 µm alumina	80	50.9	51.2	1.473	0.311
0.5 µm cerium oxide	80	55.7	54.1	1.472	0.443

For 1 µm diamond, Kihara, et. al. [5] found a layer index of 1.535 and a thickness of .113 µm, which reasonably match our calculated values for 1 µm diamond.

To better analyze the data, the 1310nm back reflection and some index of refraction and thickness trends from Table 1 are depicted in Figures 2 thru 6.

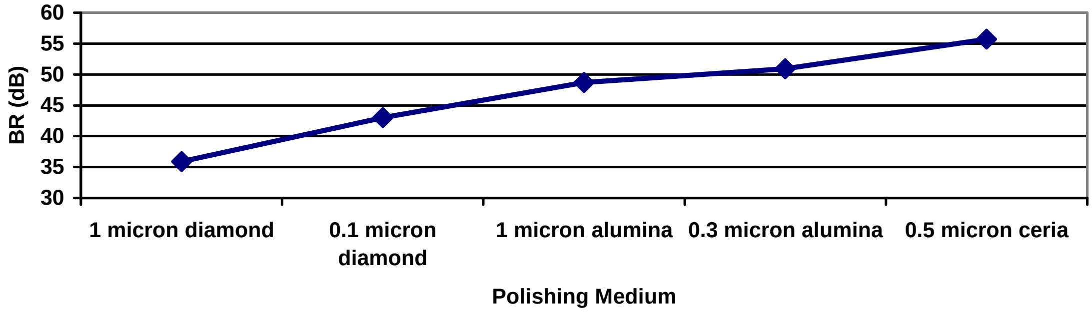

Fig. 2. Comparison of Average BR vs. Polishing Media for constant 80 gram force

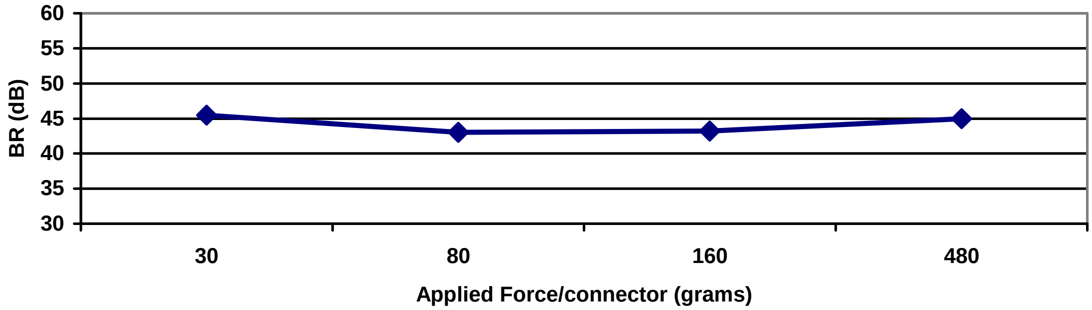

Fig. 3. Average BR vs. Force, 0.1 micron diamond

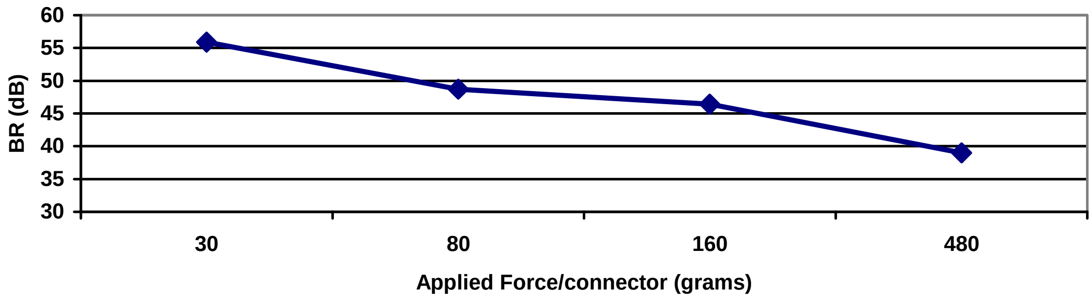

Fig. 4. Average BR vs. Force, 1 micron alumina

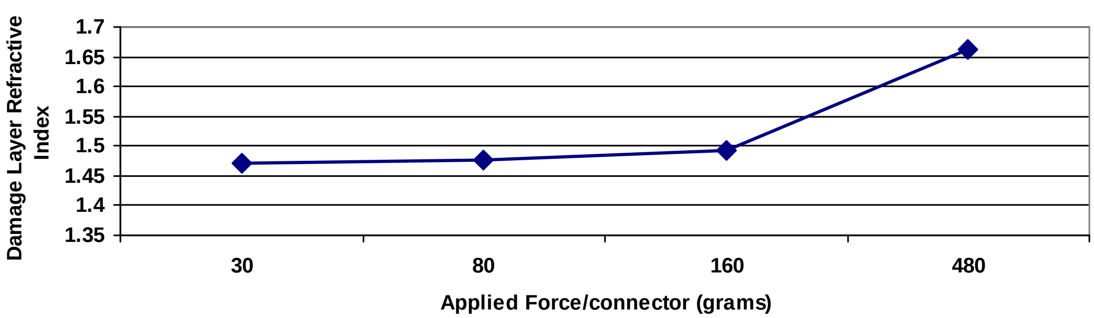

Fig. 5. Layer Index vs. Force - 1 micron alumina

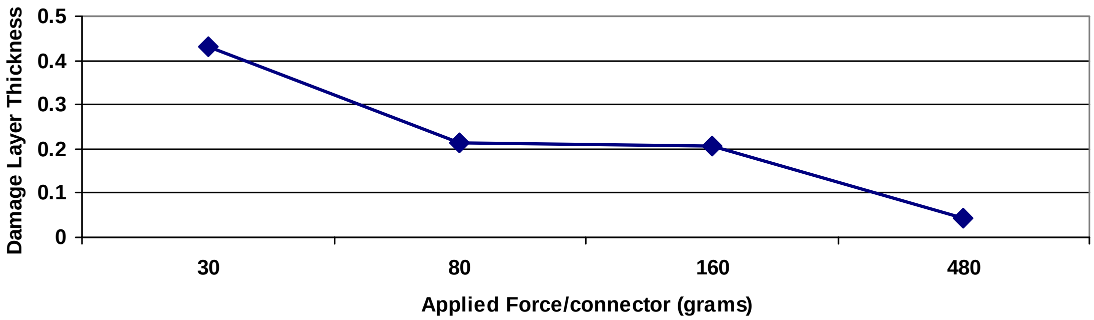

Fig. 6. Layer Thickness vs. Force - 1 micron alumina

From the above graphs, several trends are apparent:

1. The layer thickness and refractive index are strong functions of the final polishing medium.
2. For 1 micron alumina, the layer thickness and refractive index are strong functions of polishing force.
3. For 0.1 micron diamond, the layer thickness and refractive index are weak functions of polishing force. These results are similar to those obtained by Lin [6].
4. There is a correlation between particle size and layer thickness and index.

As discerned from Figures 2 thru 6 and Table 1, very poor back reflections (~ 35 to 45dB) are achieved from the diamond regardless of its grain size. This is because the diamond most damages the glass, compacting it, and yielding the high damage layer refractive indices (~1.5) regardless of the pressure applied. Lin [6] found a slight decrease in back reflections with decreasing pressure (applied force/connector). However, a much smaller range of applied forces were considered in that work.

Quite a different trend is seen with alumina. Poorer back reflections are achieved only when the polishing forces are greatly increased. When working at very low force, extremely good back reflections are attainable, in excess of 55dB at 1310 nm for 1 µm alumina!

As anticipated, smaller grain sizes of alumina and diamond induce less significant high index damage layers on the fiber end faces allowing better back reflections (i.e., 50 dB and greater) to be achieved.. Also, as alumina and ceria are less hard than diamond they appear to induce less significant high index damage layers.

Finally, note that the layer thickness *increases* with decreasing force. This suggests that there are several layers with different indices, rather than one discrete layer. More likely, there is a continual change in the index and we are measuring an effective composite value of the high index damage layer.

6. Conclusions

Dual wavelength reflectometry is shown to be an effective test method to non-destructively measure the size and refractive index of an optical connector's high index damage layer. Utilization of this method has revealed that when working at very low force, extremely good back reflections, in excess of 55dB, are attainable from a 1 µm alumina final polishing step.

Future work will be to study theses same effects of varying polishing pressures and times for standard silica oxide abrasives whereby "Hyper PC" return loss performance may ultimately be readily attainable from polishing machines that can provide suitable force control, such the Sagitta Gemini-Cx processing cell.

7. References

[1] International Electrotechnical Commission (IEC) 61755-1 CD, “Fibre Optic Interconnecting Devices and Passive Components”, IEC 86B/1816/CD, Page 9 Figure 3.

[2] GR-326-CORE, “Generic Requirements for Singlemode Optical Connectors and Jumper Assemblies,” Issue 3, September 1999.

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[4] K. Kanayama, et al., "Evaluation Method and Performance of Advanced Low-Reflection Optical Connectors", International Wire & Cable Symposium Proceedings 1992, pp. 785-791.

[5] M. Kihara, et al., "Return Loss Characteristics of Optical Fiber Connectors", Journal of Lightwave Technology, Vol. 14 No. 9, September 1996.

[6] S. Lin, "Effect of Polishing Conditions on Terminating Optical Connectors with Spherical Convex Polished Ends", Applied Optics, Vol. 41, No. 1, January 2002