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Fiber optic mirror fabrication using general-purpose metallic pigments

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ABSTRACT

In this work, the potential of using general-purpose paints to fabricate highly reflective, low-cost optical mirrors is evaluated. The study shows that high-reflectivity mirrors can be created in standard single-mode fiber in a reliable, simple and economic manner using the appropriate metallic paint. Preliminary results confirm that the grain size of the metallic particles is a crucial factor in the reflective behavior, together with the substrate in which the particles are suspended. Moreover, interferometric patterns have been observed in some cases, which could lead to the creation of simple and economic fiber optic sensors.

Keywords: Optical fiber, mirror, reflector, fiber-based device

1. INTRODUCTION

Academic interest into optical fiber sensors remains high, due to the many advantages they provide over traditional sensing methods. This technology offers small devices capable of functioning under hazardous conditions such as high electromagnetic interferences or the presence of dangerous chemicals as well as allowing for remote sensing [1]. There are several types of approaches in fiber optic sensors; some of them using fiber optic reflectors/mirrors at the end of the fiber. For example, interferometric approaches and probe-type sensors have proven capable of highly effective performance and compact size [2]. Therefore, the importance of fiber optic mirror in this research area cannot be understated.

The cleaved surface of optical fiber is inherently reflective. However, the rates of reflection this surface offers, considering standard single-mode fiber-to-air transition is around ~4%. As a result, the creation of mirrors on the fiber tip to enhance the reflectivity is a common practice. There are many techniques that allow for the creation of reflective end-surfaces with different particle size and reflection rates. However, most of these techniques are relatively complex and require the use of expensive materials and technologies. Sputtering is one of such techniques. This method is often combined with materials such as gold or silver to create a reflective layer directly over the fiber surface, resulting in high reflection ratios. However, this method requires specialized equipment that may not be always available [3]. Similar reflectivity can be achieved through the use of electron-beam vapor deposition but this also requires high-end specialized equipment [4]. A less known but highly effective technique is atomic layer deposition (ALD), which has proven capable of creating extremely reflective surfaces. However, this technique also requires the use of costly specialized equipment [5]. An alternative and simpler method is the application of Tollen’s reagent. While it does not require the use of specialized equipment, the solution must be prepared in situ and immediately applied on the fiber. This fact, combined with the precision needed for an adequate reaction and application of the coating, may cause this option not to be suitable for use in a reliable, low-cost operation.[6] Some low-cost approaches such as dipping the fiber into molten, low-melting-point metal alloys have been tested but these result in significantly lower reflection rates[7]. A summary of the different techniques to create fiber optic mirror can be seen in Table 1.

Table 1. Comparison of different techniques used for the creation of optical fiber mirrors and their results.

Technique	Reflectivity	Grain size	References
Dipping the fiber into low-melting-point metal alloy	43% -60 %	N/A	[7][8]
ALD	99 %	4-200 nm	[5] [9]
Sputtering	95%	<50 nm	[3] [10]
Tollen’s reagent	80-95%	60-200 nm	[6][11]
Electron beam evaporator	95%	<100 nm	[4][12]

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In this work, an alternative solution using general-purpose commercial metallic pigments to fabricate low-cost, high-reflectivity fiber optic mirrors is proposed. A study of 5 commercially available paints is carried out, evaluating their performance as fiber-optic mirror. Results show that some solutions can achieve a reflectivity as high as 90%, using a low-cost paint. Moreover, the fabrication process is quick, simple, and can be done directly on the structure tip without any other consideration. The metallic particle size, as expected, has a high impact in the performance. Finally, interferometric patterns can be observed in some samples, which could lead to the design of simple sensor devices.

2. METHODOLOGY

In order to test the effects of different types of coatings, a total of 5 general-purpose paints with different textures and intended applications have been selected based in their apparent reflectivity. To simplify the identification of the samples during the study, a letter has been assigned to each paint in the following manner: *A* corresponds to Molotow Liquid Chrome [13], *B* to Cadence mirror effect [14], *C* to L.A.B. Cromatica Acrilica [15], *D* to Titanlux Acualux 859[16], and *E* to Maurer Spray 933483[17]. Ten samples of each material have been prepared and analyzed using two different analysis methods: a reflectivity measurement using an optical spectrum analyzer and Scanning Electron Microscopy-Energy Dispersive X-Ray (SEM-EDX) analysis.

In order to perform this analysis, we have used a Superluminescent Light Emitting Diode (SLED) as a broadband light source connected to the Optical Spectrum Analyzer (OSA) and to the sample using a 3-port optical circulator. The inclusion of the circulator results in additional losses being introduced to the setup. Therefore, a reference measurement was done using a gold-coated reference mirror commonly used to calibrate high-precision optical frequency-domain reflectometers. The optical spectrums have been measured in wavelength range between 1450 and 1650 nm.

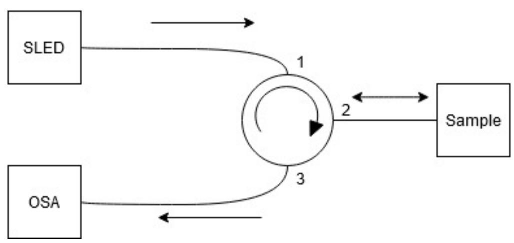


Figure 1. Setup used for the experiment.

The main objective of this analysis is to measure the reflectivity of the fabricated mirror. However, each sample reflectivity not only correlates with the coating, but it also depends on the inherent reflection of the cleaved fiber surface. To obtain an accurate measurement of the paint's reflectivity, each sample has had its optical spectrum analyzed twice: before and after the paint's application. This allows us to gauge the improvements caused by the coating. Finally, a SEM-EDX analysis has been performed to infer how the particle size, density and composition may influence its effectivity as an optical reflector.

3. RESULTS

First, ten samples of each A and B products were prepared just by dipping the fiber tip into the paint itself, after cleaving and cleaning. In nine out of the ten samples, the paint was applied successfully. The optical spectrum of these samples can be seen in Fig. 2(a), with the insertion losses compensated using the reference gold mirror to obtain the reflectivity. The reflection given by the fiber end just after the cleave present an expected reflectivity around -14.4 - -15,2 dB (3.6-3%). After applying paint *A* to the fiber end, the reflectivity increased to -12.2 – 6.0 dB (5.8-22.4%) at 1550nm which is an significant increase over the cleaved fiber. However, the results display high variability (>6 dB) depending on the application, showing a non-flat pattern in some cases. The mirrors created using the product *B* present a flat wavelength response with a reflectivity at 1550 nm between -0.45-0.82 dB (90-83%). Furthermore, the consistency of the results is high after a correct application of the paint.

The results obtained using *C, D* and *E* products were inconsistent, obtaining lower reflection ratios than the given by the fiber with a cleaved end. Out of ten samples barely 1 or 2 had a relatively flat spectrum, but reflectivities ranged between 5-25% at most in such cases. The rest of the cases presented inconsistent behaviors, with a reflected power even lower than the cleaved end. For the sake of clarity, the results of only one sample of each product *C, D* and *E* are represented separately in Fig. 2(b), together with the reference mirror and the cleaved-end fiber reflector. It is clear that these products cannot be used to create reliable mirrors, at least straightforwardly. However, some interferometric patterns can be observed in the results, probably related with the particle size and the substrate material for the metallic particles. Further analysis is being done to evaluate the possibility of using these products to fabricate simple interferometric sensors.

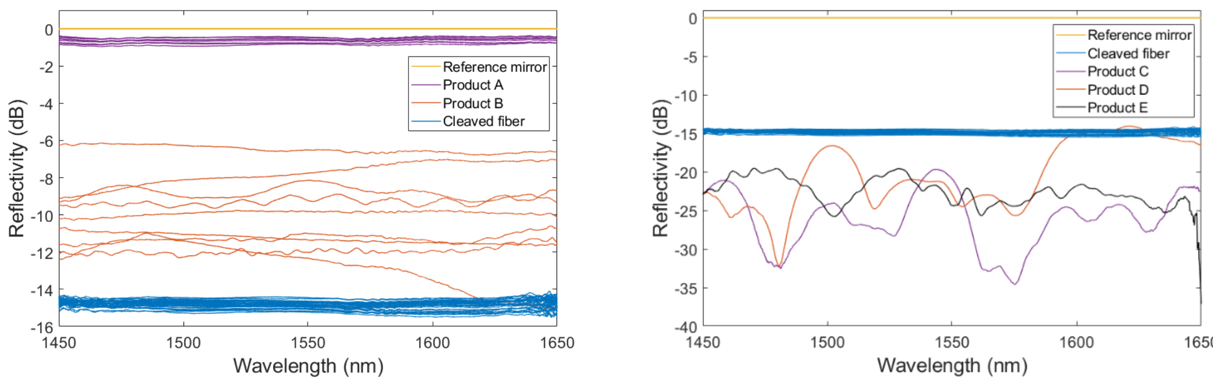
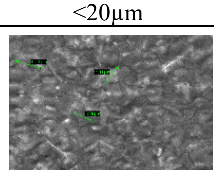
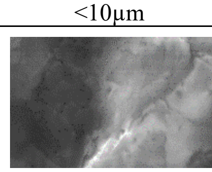
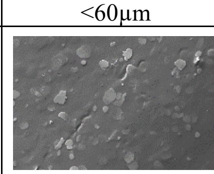
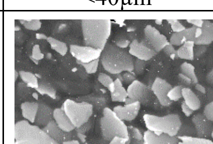
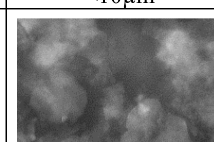


Figure 2:Measured reflectivity of reference gold mirror, fiber cleaved-end and samples A and B (a) and C, D and E (b).

Regarding the SEM-EDX analysis, the metallic particle sizes were estimated, showing an expected correlation between particle size and reflectivity, with smaller sizes yielding the best results. On the other hand, the analysis showed that *C* and *D* products had mainly a polymeric base, which could be related to the interferometric patterns observed. Moreover, the variability of particle size displayed by *C* and *D* may be responsible for the highly volatile results achieved during the optical spectrum analysis. Table 2 shows a summary of the results, considering 9 to10 samples of each type at 1550nm for the calculations. Note that the results of *C, D* and *E* are significantly worsened by the high rate of failed depositions. Better results would be obtained by contemplating only the successful cases, but those represent less than the 15%.

Table 2. Summary of the results for products *A* to *E*.

	A	**B**	**C**	**D**	**E**
Material	Molotow Liquid Chrome [13]	Cadence Mirror Effect [14]	L.A.B. Cromatica Acrilica [15]	Titanlux Acualux 859 [16]	Maurer Spray 933483 [17]
Average Reflectivity	11.6%	86.8%	3.4%	1.6%	1.6%
Standard deviation	0.056	0.028	0.072	0.017	0.017
Maximum Reflectivity	22.3%	90.1%	23.6%	5.7%	5.1%
Minimum Reflectivity	5.9%	82.7%	0%	0%	0.1%
Particle size	<20μm	<10μm	<60μm	<40μm	<10μm
SEM-EDX analysis					

4. CONCLUSIONS

In conclusion, the study has shown that general-purpose available metallic pigments can be used to fabricate fiber optic mirrors with a reflectivity around 80-90% in a simple, quick and low-cost manner. Out of 5 products, 2 showed a significant reflectivity increase, with one of them achieving outstanding results (over 80%). The best results are achieved by using paints with smaller particle sizes and mainly organic solvents substrates which allows better fiber deposition. The quality of the cleave on which the mirror is created is also an important factor to consider if aiming for the fabrication of high-quality reflectors. Finally, interferometric patterns have been observed in some cases. Further work is being done to evaluate the possibility of creating simple interferometric sensors.

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