500°C-Rated Optical Fibers for High Temperature Applications

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Abstract

Optical fibers for high temperature applications (> 300°C) have typically been metal-coated. These fibers suffer high attenuation (> 10 dB/km), and are limited in length. This paper describes a low-attenuation metal-coated fiber operating at temperatures up to 500°C.

Keywords: metal coating, harsh environment, DTS, supercritical geothermal, downhole

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I Introduction

Silica-based glass optical fibers without coating can withstand temperatures greater than 600°C. However, glass fibers need to be protected from the environment. Standard telecom fibers are typically coated with acrylate that allow their use in temperatures up to 85°C. Specialty optical fibers can be produced with a polyimide coating, which allows these fibers to be used in environments up to 300°C. This type of fiber has been used extensively in the oil and gas industry to provide important communications and sensing functions for reservoir management.

For temperatures above 300°C, metal coatings would be attractive. Those produced to date have been deemed unsuitable for geothermal well deployment due to high attenuation values at low temperatures[1]. Downstream oil processing can also benefit from high temperature measurements requiring low attenuation fibers that perform beyond 300°C. This attenuation as well as significant attenuation changes during cycling is generally attributed to micro-bending and the large mismatch of the coefficients of thermal expansion between the metal coating and the glass fiber[2]. Among other things, thinner metal coatings could help to mitigate these issues; however, the production of long lengths of high quality metal-coated fiber with controlled thickness of the coating is non-trivial[2].

In this paper, a metal-coated fiber capable of withstanding temperatures up to 500°C will be demonstrated. In addition, it will be shown that this fiber can be cycled between room temperature and 500°C, while maintaining low attenuation even at low temperatures.

II Fiber Design

It has been demonstrated since the early 1980s that hydrogen ingression in silica-based glass induces losses in optical fibers at specific wavelengths due to the absorption of a variety of hydrogen related species[3]. Common silica fibers used in communications such as standard single-mode (SM) and standard graded-index multimode (MM) suffer a dramatic optical degradation in presence of hydrogen even at room temperature. The cores of these fibers are typically doped with refractive index increasing elements such as germanium and phosphorus. Depending on the temperature and H_2 concentration, once hydrogen diffuses in the fiber core, it can migrate to interstitial sites of the structure and/or bond with existing defects in the glass such as SiO, GeO and P-O. The overall fiber loss reaches hundreds of decibels per kilometer, which makes it unusable for any light transmission applications.

AFL took an innovative approach to prevent the optical degradation of optical fibers immersed in a harsh environment by modifying and optimizing the design of the glass component of the fiber itself. In particular, the approach consists of eliminating the dopants that create more defects in the glass structure such as germanium, phosphorus, and boron. The fiber is designed with only silica in the core, along with fluorine doping to achieve the graded index profile of the multimode fiber[4]. This fiber is produced by AFL and is branded as Verrillon® VHM5000; it is a 0.2 NA 50/125µm GI-MMF.

VHM5000 was the base fiber used with this metal coating. It had a gold-based coating with a wall thickness of approximately 3 - 5 µm which is well below the typical coating thickness of 15 – 25 µm for commercially available metal-coated fibers. A cross-sectional SEM image demonstrating the good concentricity and integrity of the coating process is shown in Figure 1.

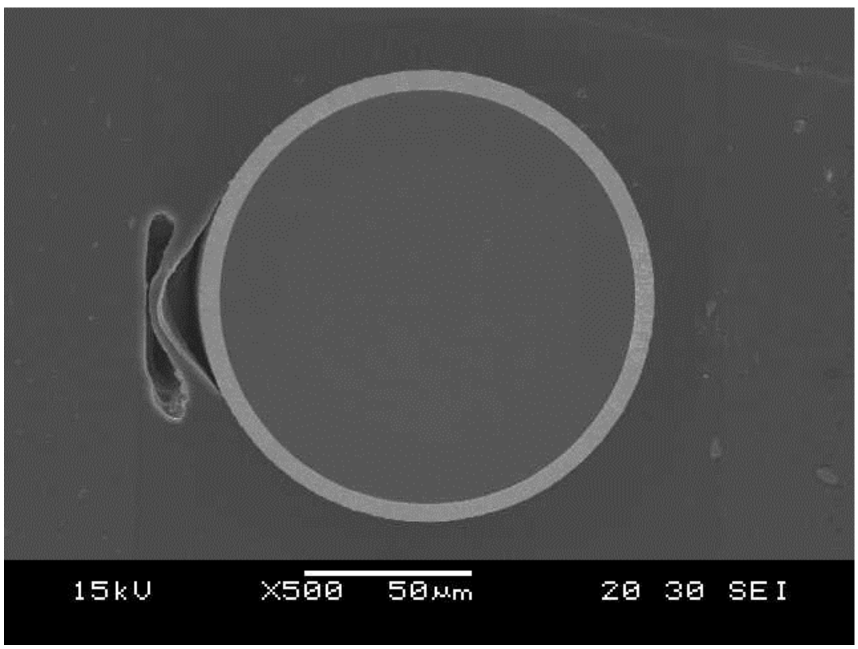

Figure 1: SEM cross-section of fiber produced using the current process

Metal-coated fibers can have optical losses in as-drawn condition as high as 20–100 dB/km at room temperature[2]. Figure 2 shows the spectral attenuation of VHM5000 with a gold-based coating shown in Figure 1, at room temperature, measured on 88m of fiber. Fiber was measured in a 300mm diameter loose coil.

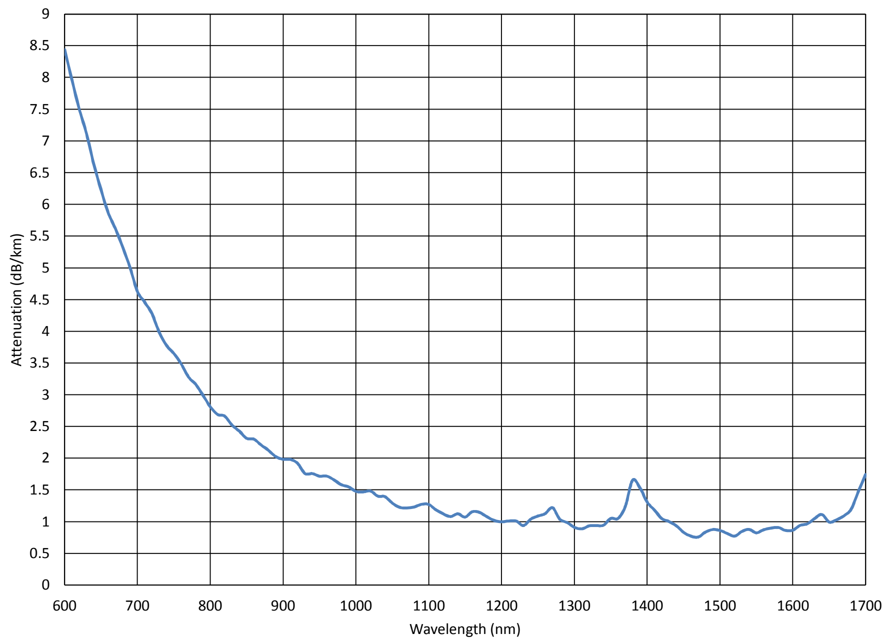

Figure 2: Spectral attenuation of VHM5000 with gold-based coating, 88m long, 300mm diameter loose coil, room temperature

The spectral attenuation of this fiber with a gold-based coating shows attenuation levels similar to standard acrylate or polyimide coated multimode fibers, as opposed to the significantly higher levels shown by other commercially available metal-coated multimode fibers.

Metal-coated fibers also have the tendency to 'cold bond' to other metals, or itself, at temperatures significantly below their melting temperature. AFL has a patent-pending process which prevents these metal-coated fibers from bonding. This process was applied to all the fibers in these tests.

III Results and Discussion

Figure 3 shows six temperature cycles of VHM5000 with gold based coating, between room temperature and 375°C. Data was acquired every 5 minutes using an OTDR. The fiber was in a 114mm loose coil, 40 meters in length. Each cycle consisted of a 30°C / hour ramp to 375°C, the temperature was held at 375°C for 24 hours, and then it was ramped down 30°C / hour until 60°C. At that point, the oven was allowed to return to room temperature, and then the next cycle was started. 850nm was the wavelength that was monitored.

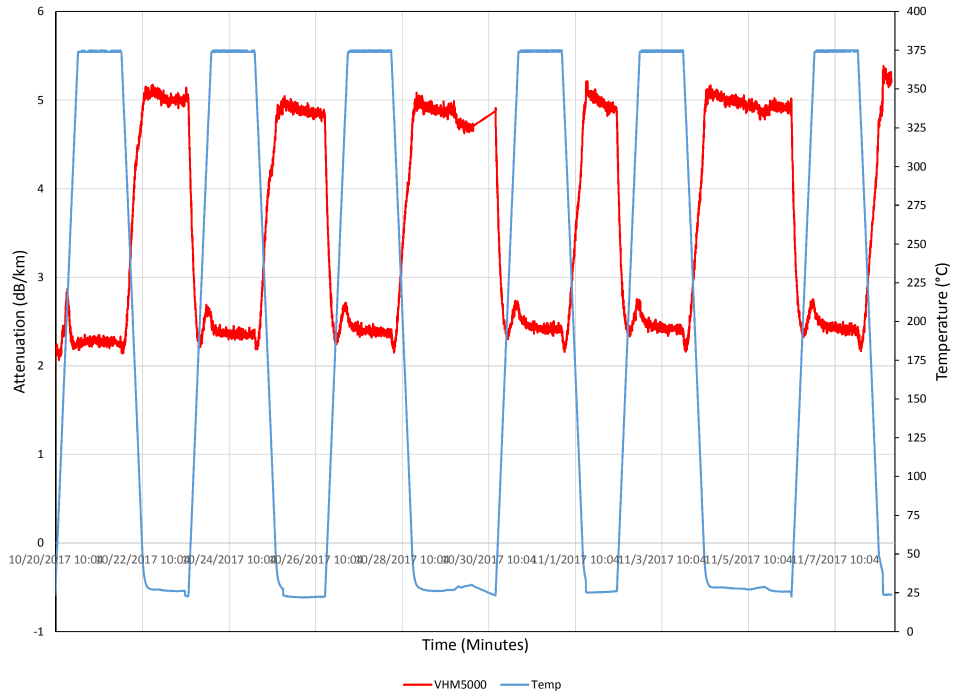

Figure 3: VHM5000 with gold-based coating, 40m long, 850nm attenuation, six temperature cycles between room temperature and 375°C

43 meters of VHM5000 gold-based coated fiber was put in a 500°C oven for 900 hours. An OTDR was connected to the fiber at the conclusion of the 900 hours, and a 500°C cycle was run. Figure 4 shows this temperature cycle, between room temperature and 500°C. Data was acquired every 5 minutes. The fiber was in a 114mm loose coil. The cycle consisted of a 30°C / hour ramp to 500°C, the temperature was held at 500°C for 34 hours, and the oven was stopped and allowed to return to room temperature on its own. 850nm was the wavelength that was evaluated.

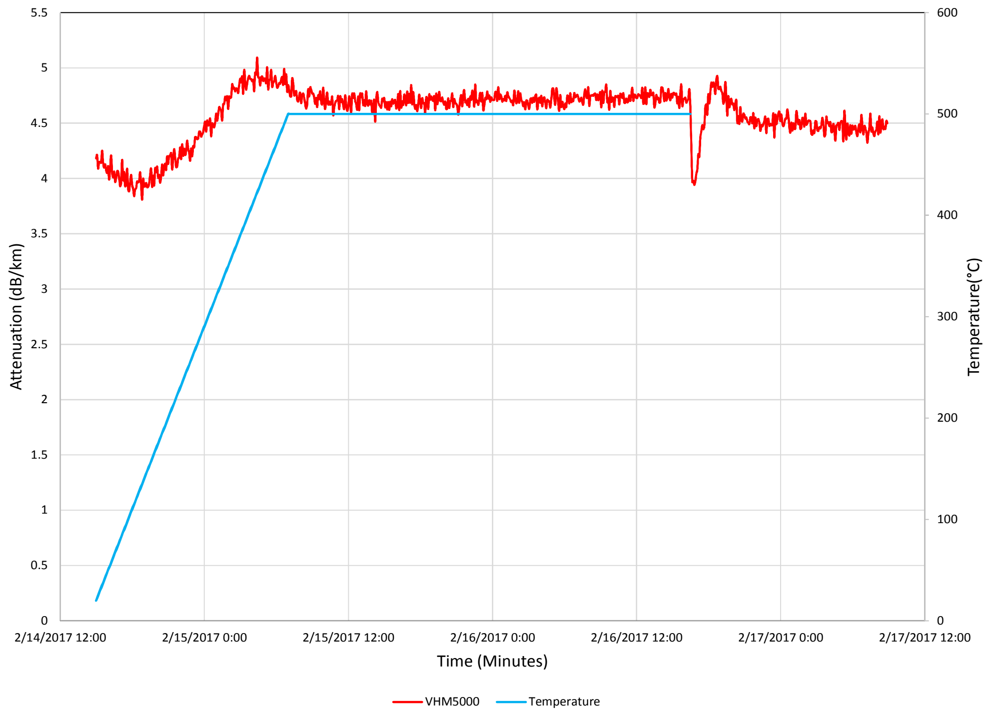

Figure 4: VHM5000 with gold-based coating, 43m length, 850nm attenuation, 34 hours at 500°C after soaking at 500°C for 900 hours

IV Conclusions

A low attenuation metal-coated optical fiber capable of withstanding temperatures up to 500°C was demonstrated. Performance was validated using an OTDR. Temperature cycling showed that the metal-coated fiber could withstand the expansion and contraction of the metal coating repeated multiple times. Attenuation at both room temperature and high temperature was significantly lower than any reported attenuation in metal-coated fibers. The 900 hour soak, and subsequent evaluation of the fiber, showed that the fiber still performed well after long-term exposure at 500°C. In addition, this process is capable of producing long length of fiber, up to 3.5km continuous.

References

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