

Relative Humidity Sensor using Tungsten Disulfide Coated on Tapered Microfiber

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Abstract

A two-dimensional transition-metal dichalcogenide material, such as tungsten disulfide (WS₂), can be used to enhance the sensitivity of certain sensing applications. The impact of WS₂ coating on tapered region microfiber (MF) for relative humidity (RH) sensing applications was examined in this work. The typical single-mode fiber (SMF) was tapered using the flame brushing technique to achieve a microfiber with a waist diameter of approximately 3 μ m. The drop-casting process, a simple deposition technique, was then used to coat the microfiber in WS₂. Depositing WS₂ onto the tapered zone resulted in high humidity sensor sensitivity because the MF had a strong evanescent field that enabled quick near-field interaction between the directed light and the environment. To demonstrate repeatability and sensor stability, the experiments were repeated three times to quantify the average transmitted power. Different relative humidity (%RH) concentrations were evaluated using multiple microfiber (MF) samples to ensure repeatability. Additionally, at room temperature and in the %RH range of 40% to 60% RH, the performances of coated and uncoated microfibers were examined. Thus, microfiber coated with WS₂ enhances the evanescent field effect in optical fiber humidity sensors.

1. Introduction

Optical fibers are widely used for signal transmission in communication systems. Beyond telecommunications, they are also applied in areas such as medicine and sensing, due to advantages such as low signal loss, high bandwidth, and immunity to electromagnetic interference.

Various fiber-based sensors have been developed, including photonic crystal fibers (PCFs), fiber Bragg gratings (FBGs), long-period gratings (LPGs), and Mach-Zehnder interferometers (MZIs) [1], [2], [3]. While these sensors offer excellent sensitivity, they are often costly and complex to fabricate.

Tapered fibers, in particular, have shown improved sensitivity in humidity sensing due to their enhanced evanescent field [3], [4]. Two-dimensional materials such as WS₂ have also been explored for improving the sensitivity of optical fiber humidity sensors due to their large surface area and strong light-matter interaction [4], [5].

Although studies such as [4] have demonstrated the effectiveness of WS₂-coated tapered microfibers for humidity sensing, most prior work does not examine the effect of coating volume or limit their investigation to broader RH ranges. This study aims to evaluate the influence of WS₂ coating thickness, using 2 μ L and 4 μ L drop-casting volumes, on sensor performance within a controlled 40 - 60% RH range. The findings provide insights into optimizing 2D material deposition for enhanced evanescent field interaction and improved sensor linearity.

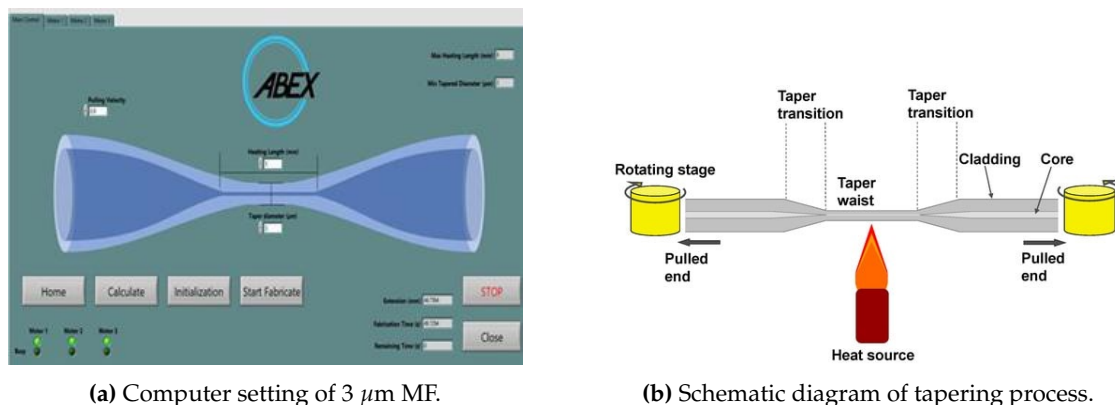
2. Experiment, Result and Discussion

The first part of the experiment was to fabricate the tapered microfiber using the flame brushing technique. A standard 125 μm SMF-28 fiber was used. The outer plastic coating was carefully stripped, and the fiber was mounted on fiber holders for alignment.

The exposed section was then gradually heated using a controlled flame while both ends of the fiber were simultaneously pulled. Stepper motors controlled by a programmable logic controller (PLC) were used to ensure uniform tapering. To ignite the flame, the oxygen valve was opened until the pressure gauge exceeded 20 psi, and the gas and oxygen knobs were adjusted slightly. The flame was then lit with a spark. A small, stable flame was maintained throughout the process to avoid burning the fiber. The gas and oxygen flow rates were adjusted continuously to stabilize the flame. The goal was to produce a tapered microfiber with a waist diameter of approximately 3 μm [3].

After tapering, the microfiber was coated with WS_2 using the drop-casting technique, which involves depositing a small liquid droplet directly onto the tapered region. In this study, 2 μL and 4 μL volumes of WS_2 dispersion were used. The selected volumes were based on preliminary trials indicating that volumes below 1 μL led to insufficient coverage, while volumes above 5 μL caused non-uniform deposition and potential flake aggregation. Although the uniformity was not quantified, visual inspection under an optical microscope showed consistent WS_2 distribution along the tapered zone.

Figure 1 shows the tapering setup and computer interface used to fabricate the microfiber.



(a) Computer setting of 3 μm MF.

(b) Schematic diagram of tapering process.

Figure 1. Tapering setup and computer interface used to fabricate the microfiber

The performance of the microfiber sensor, both before and after WS_2 coating, was evaluated for relative humidity (RH) sensing. Figure 2 shows the setup used to test the sensor's response to different RH levels. A sealed chamber was prepared with a 3 μm microfiber connected to a tunable laser source (TLS) and an optical power meter (OPM). A commercial hygrometer was placed inside the chamber to monitor humidity levels.

The experiment was conducted at room temperature (25 $^{\circ}\text{C}$). Relative humidity was varied from 40% to 60% by placing a drop of water mixed with sodium hydroxide (NaOH) inside the chamber, a common method to create a controlled RH environment [5]. The TLS was set to 1550 nm, and the transmitted power was recorded using the OPM. To ensure consistency and repeatability, each test was conducted three times using different microfiber samples.

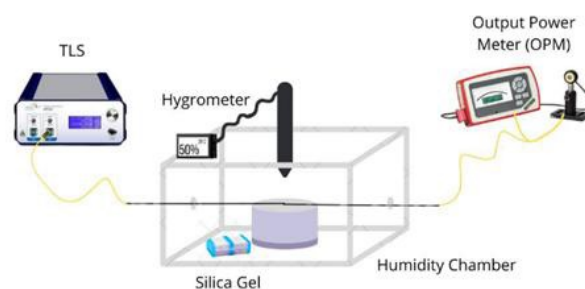


Figure 2. Experimental setup for microfiber relative humidity sensing



The linearity and sensitivity of the sensor were measured to compare the performance of WS₂-coated and uncoated microfiber. Figure 3 shows the sensor response for different coating volumes, where the inclusion of WS₂ improves both sensitivity and linearity by approximately 7%, which is consistent with results reported in similar studies [1], [3], [5]. The error bars in the graph represent the standard deviation from three repeated measurements, indicating good repeatability. Table 1 summarizes the performance metrics for the uncoated and coated microfibers. These results support the use of WS₂ for enhancing the evanescent field interaction, enabling better detection of humidity variations.

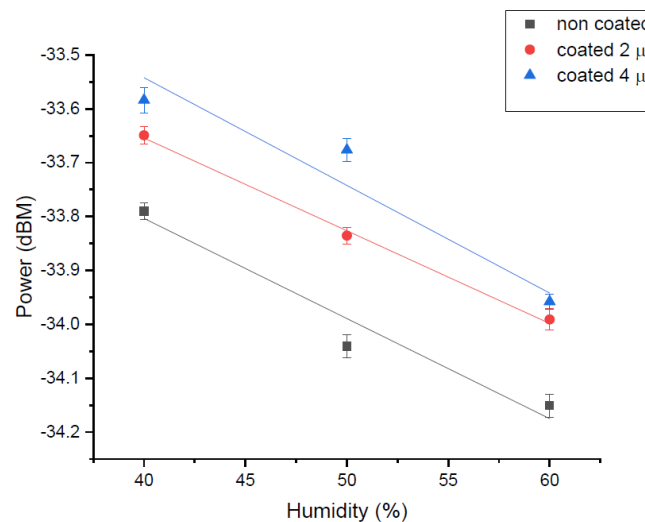


Figure 3. Sensor performance with different WS₂ coating volumes (2 µL and 4 µL). Error bars represent standard deviation across three measurements for each sample.

Table 1. Analysis of diameter of microfiber with WS₂ performance in humidity sensing

Parameter	Non-Coated	Coated 2µL	Coated 4µL
Linearity	0.96	0.98	0.989
Sensitivity(dBm/%RH)	0.0172	0.01858	0.01998
Linear Range (%RH)	40-60	40-60	40-60

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