

Improve Formaldehyde Vapor Sensing

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Keywords

Tapered optical fiber
Formaldehyde
Rhenium Disulfide
sensitivity
sensor

Article History

Received: 16 May 2025

Accepted: 5 June 2025

Published: 15 November 2025

Abstract

Formaldehyde (CH_2O) is a toxic, colourless, and flammable gas that is widely used in various industries and household products. Current formaldehyde detection methods often suffer from limitations such as low sensitivity, high cost, and impracticality for widespread use in residential and industrial settings. This study focuses on evaluating the performance of uncoated and Rhenium Disulfide (ReS_2)-coated tapered optical fibers (TOFs) in detecting formaldehyde, using fibers with a waist diameter of $10\text{ }\mu\text{m}$ and a length of 3 mm . The experimental evaluation was conducted by exposing the TOFs to formaldehyde vapor concentrations of 1%, 2%, 3%, 4%, and 5%, under relative humidity conditions ranging from 30% to 90%. The results show that the ReS_2 -coated TOFs demonstrated better sensitivity in detecting formaldehyde compared to uncoated TOFs with measured sensitivities of $-0.03245\text{ dBm}/\%$ and $-0.00371\text{ dBm}/\%$ at 5% formaldehyde concentration. Overall, formaldehyde sensing performance can be improved by coating the TOFs with ReS_2 , with sensitivity increasing by more than 80% compared to the uncoated fibers.

1. Introduction

Formaldehyde is a colourless, flammable gas with a sharp odour and is commonly found in both industrial and residential environments. It is widely used in the production of resin-based wood products, building materials, household items, cosmetics, and pesticides. However, formaldehyde exposure poses significant health hazards. Short-term exposure can cause irritation to the eyes, nose, and throat, while long-term exposure has been linked to an increased risk of cancer [1], [2]. Due to its widespread use and toxic nature, reliable monitoring of formaldehyde concentration, especially in indoor and industrial airspaces, is essential to ensure environmental and occupational safety. Currently, most formaldehyde detection technologies, such as electronic sensors, offer good accuracy but are expensive and not suitable for widespread or low-cost deployment, particularly in residential settings. Furthermore, many existing sensors suffer from limitations such as low sensitivity, high power consumption, and restricted functionality under varying environmental conditions. Therefore, there is a growing need for alternative sensing technologies that are cost-effective, highly sensitive, and adaptable. Tapered optical fibers (TOFs) coated with Rhenium Disulfide (ReS_2) have emerged as a promising alternative. ReS_2 , a two-dimensional material, possesses a tunable bandgap and high sensitivity to refractive index changes, making it ideal for gas sensing applications [1]. In this work, TOFs were fabricated using the heat-pull method and tested for formaldehyde detection at concentrations ranging from 1% to 5% and under relative humidity levels from 20% to 90%. The performance of both uncoated and ReS_2 -coated TOFs was evaluated using a 1550 nm tunable light source and an optical power meter.

2. Results and Discussion

In this research, TOFs were fabricated using heat and pull method with $10\text{ }\mu\text{m}$ waist size diameter. In the first part of experiment, the performance of uncoated TOF is evaluated and compared to the performance of TOF coated with $20\text{ }\mu\text{m}$ ReS_2 . For this experiment, the formaldehyde concentration is varied from 1% to 5% with vapor level from 30% to 90%. Figure 1 shows the fabricated TOF $10\text{ }\mu\text{m}$ under Dino Lite Microscope with 510.3 magnification. For fabricating $10\text{ }\mu\text{m}$ TOF took 46s fabrication for 3 mm TOF length with pulling velocity 0.5 m/s [3].



Figure 1. Dino Lite Microscope for sample 10 μm TOF

In the first part of experiment, the performance of uncoated TOF is evaluate and compare the performance by coated with 20 μm ReS_2 . The figure illustrates that the 10 μm TOF tested on 1% level of formaldehyde concentration has lowest value of slope. As can be seen, the 1% formaldehyde has the highest output power obtained which is about 20% to 30% difference to other levels of concentration. The 2% and 4% formaldehyde concentrations have quite the same slope which at $-0.00203 \text{ dBm}/\% \text{RH}$ and $-0.00201 \text{ dB}/\% \text{RH}$ as depicted in Figure 2.

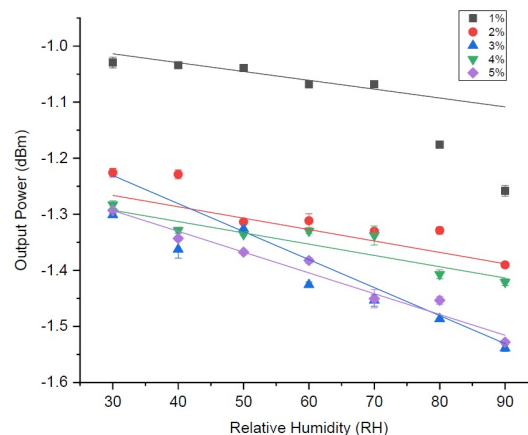


Figure 2. The output power for uncoated 10 μm TOF

In the end of this paper, the performance of coated and uncoated TOF for 5% formaldehydes concentration is plotted in Figure 3. Based on the results, sensitivity for coated is increased almost 80% compared to non-coated TOF with sensitivity $-0.03245 \text{ dBm}/\% \text{RH}$ and $0.00371 \text{ dBm}/\% \text{RH}$ of formaldehyde vapor.

3. Conclusion

This study successfully demonstrated the enhanced performance of Rhenium Disulfide (ReS_2)-coated tapered optical fibers (TOFs) in detecting formaldehyde vapor. The uncoated TOFs exhibited inconsistent output trends and lower sensitivity across the concentration range. In contrast, the ReS_2 -coated TOFs showed a more consistent and linear response, with significantly higher sensitivity. Specifically, the coated TOF achieved up to an 80% improvement in sensitivity compared to the uncoated version, with measured sensitivities of $-0.03245 \text{ dBm}/\%$ and $-0.00371 \text{ dBm}/\%$ at 5% formaldehyde concentration, respectively. These findings validate the potential of ReS_2 -coated TOFs as cost-effective and highly sensitive sensors for formaldehyde vapor detection under varied humidity conditions.

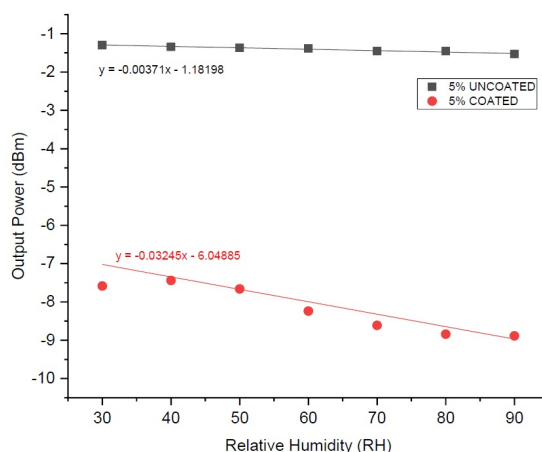


Figure 3. Sensor performance for coated and uncoated ReS₂ at 5% formadehyde concentration

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