A new method of ethanol catalytic deposition of MoS_2 on tapered fiber for photonic application

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***Abstract*—Ethanol catalytic deposition (ECD) on the optical tapered fiber was put forward to improve the deposition of two-dimensional (2D) MoS_2 materials to exhibit its nonlinear optical properties. This work demonstrated the acceleration of deposition due to high volatility of ethanol compared with other solvents. We believe ECD method is able to be applied to other similar 2D materials such as other types of transition metal dichalcogenides for the photonic researches such as four-wave mixing.**

Keywords—MoS2; deposition; tapered fiber;

I. INTRODUCTION

Nowadays transition metal dichalcogenides (TMDs) have received intense interest for their various promising electronic and photonic properties [2-7]. The optical intensity modulation is based on the tunable bandgap and absorption [8-10]. The wideband absorption spectrum has been provided for operation of a broadband polarizer. Among these applications led by affluent properties, optical nonlinearity of the materials nonlinear properties, namely $\chi^{(3)}$ or n_2 of the materials have been paid attention. Optical nonlinearity allows the realization of four-wave mixing which has wide applications such as wavelength conversion, frequency comb generation and microwave photonic filter. Recently, graphene has been found much higher optical nonlinearity than that in a classical silica fiber, which suggests its potential to be a highly compact nonlinear device [11, 12]. Also, molybdenum disulfide (MoS_2) together with other types of TMDs has been discovered comparable optical nonlinearity with the graphene, which offer alternative choice of nonlinear optical materials [13-16].

On the other hand, incorporation of the TMDs into the developed fiber systems is vital for its promising properties of these materials together with the mature technologies of the fiber systems. Different incorporation methods have been developed including directly transferring the CVD grown materials to the fiber end [17-19], depositing to the fiber end [20, 21], depositing to the fiber waist of the side polished fiber or tapered fiber [22, 23], and embedding into the polymer thin film [3, 24]. Among the above methods, deposition on the fiber waist of the tapered fiber has its unique advantages, such as long interaction length for light and new materials which allows the easier realization of four-wave mixing if used in a conventional optical device. In the previous papers, the conventional method achieved the deposition solely by the using the optical force between the leaked light and MoS_2 nanosheets to attract the nanosheets to the waist or end of optical fiber[25]. The optical force must be strong enough to overcome the solvent resistance such as N,N-Dimethyl formamide (DMF).

In our works, the new method of ethanol catalytic deposition (ECD) added the Brownian motion into the process to accelerate the deposition. In this way ECD exhibited a faster deposition rate and lower deposition power than the conventional method. We believe the ECD could also benefit the deposition of other 2D materials such as other types of TMDs.

II. EXPEREMENT

MoS_2 dispersions for deposition on tapered fiber were prepared as follows: ~0.02 g MoS_2 powder was first mixed with 20 ml 95% ethanol in the glass tube. The mixture was sonicated for 1 hour to generate MoS_2 nanosheets. Then the MoS_2-ethanol mixture was centrifuged for 90 minutes to achieve well-distributed nanosheets. Finally the top 2/3 dispersion with good uniformity were collected for the experimental use. Fig.1 (a) shows the procedures of preparation of MoS_2-ethanol dispersions.

To carry out our experiment, a continuous wave laser was used to offer the optical source of 1550 nm. An erbium-doped fiber amplifier (EDFA) followed to amplify the light power to 15 dBm. A customized slide glass was set to place the tapered fiber and the light was injected from one side of the tapered fiber. A microscope was set to monitor the deposition situation and the optical power meter with an attenuator was used to record the output optical power, shown in Fig.2 (b). Difference occurs when we used ethanol as a solvent. Together with the optical force by the leaked light, the high volatility of the ethanol can accelerate the Brownian motion of MoS_2 nanosheets in the dispersions and in turn facilitate the deposition of MoS_2 in a rate faster than the conventional way.

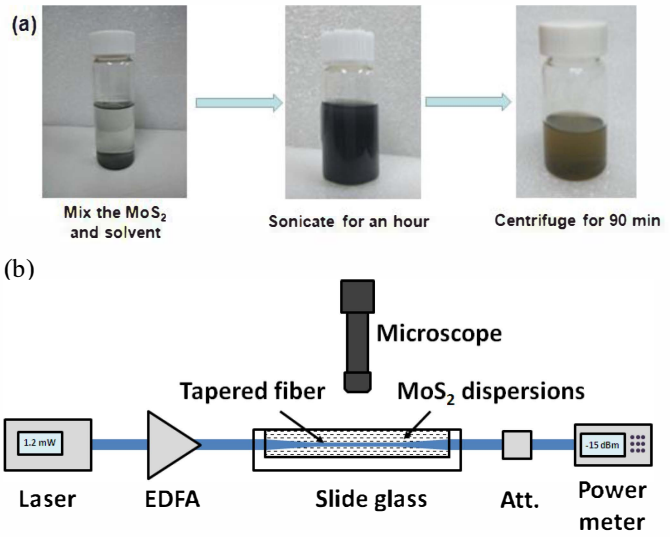

Fig.1. (a) Procedures of preparation of MoS_2-ethanol dispersions; (b) Experimental setup for ethanol catalytic MoS_2 deposition on tapered fiber.

To justify the unique effect of MoS_2-ethanol dispersions, four solvents, i.e., water, DMF, ethanol and acetone were chosen for the comparison. Other parameters were fixed including the tapered fiber diameter fixed to 10 μm and the input optical power to 15 dBm. The deposition process was recorded as shown in Fig.2 and the inset is the microscope image of the deposited MoS_2. From the figure we could find MoS_2 was successfully deposited on the surface of tapered fiber and ethanol has a relatively better deposition rate than that of water or DMF dispersions (about 18.9 and 5.1 times, respectively), which in turn suggest the volatility can be a vital parameter in the process. Also, it is interesting to see MoS_2-acetone dispersions had the fastest deposition rate for its better volatility. However, the curve exhibits a severe fluctuation that caused by high speed colliding of MoS_2 nanosheets on the tapered fiber. Thus to make the deposition in a controllable way (e.g., to obtain 10 dB loss induced by the deposited materials), ethanol is preferred because the deposition with ethanol solvent showed more smooth curve than that with acetone.

In addition, to investigate the depostion rate under different optical power levels, we reduced the optical power from 15 dBm to 0 dBm with the step of 1~2 dB. the diameter of tapered fiber was 6 μm to make power loss obvious to read under the low injected optic power. The result is shown in Fig.3. In this figure we can discribe an ever-decreasing loss rate as optic power was turned down. The dips on the graph when optical power is changed were caused by the propertises of EDFA. The inset in Fig.3 is a deposition process with EDFA on or off . The different slopes represent the different deposition rates, thus we could confirm the deposition power threshold can be as low as ~4 dBm. Compared with the minimum power to drive the deposition in the conventional methods in which the low volatile solvents were used, the ECD method allows a very low minimum power threshold and leads to a deposition easier to be realized.

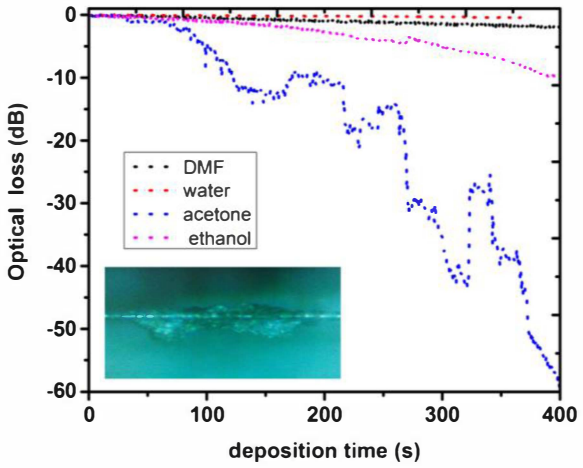

Fig.2. Deposition process using water, DMF, ethanol and acetone as solvent. Inset: microscope image of the deposited MoS_2.

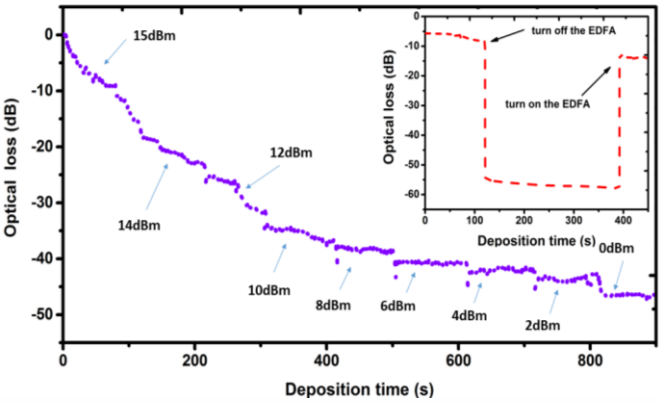

Fig.3. Deposition process under different injected optical power levels. Inset: evolution of the optical loss when the EDFA was turned off and turned on again.

To study the optimal choice of tapered fiber diameter for deposition, several different diameters, i.e. 4 μm, 6 μm, 8 μm, 10 μm and 12 μm were chosen for comparison. Other parameters were fixed, namely 15 dBm of optical power and ethanol solvent. The results are illustrated in Fig.4. Increasing deposition rates can be observed as the diameter decreases. When the diameter is larger than 12μm, almost no deposition phenomenon can be observed that indicates little optic field is leaked for interaction. On the other side when the diameter is smaller than 4 μm, the fluctuation of loss increases drastically which make the deposition process very hard to control. The reason lies in the fact that MoS_2 nanosheets deposited on the tapered fiber are easy to be removed when collided by other nanosheets moving to the fiber waist, especially when the waist is very small. The scattering loss caused by the residual large-size MoS_2 powder also becomes large with the decrease of fiber diameter. Therefore, the optimized range of fiber diameters is from 6 to 10 μm.

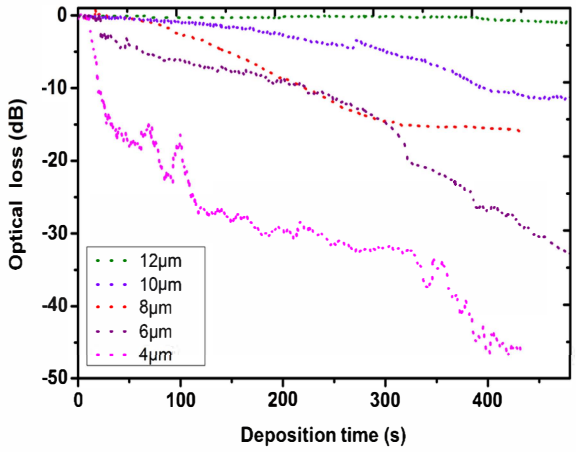

Fig.4. Deposition process using different diameters of the tapered fiber

III. CONCLUSITON

In this work, we have investigated the ethanol catalytic deposition (ECD) of MoS_2 dispersions on the tapered fiber. Due to the high volatility of the ethanol, the movement speed of MoS_2 nanosheets in the dispersions was accelerated which led to a deposition rate 5.1 times higher than that of DMF as well as a minimum power threshold to drive the deposition as low as 4 dBm. Our results demonstrated the effectiveness of the ECD method for an easy, effective and controllable deposition, which is very important in the research area such as optical nonlinearity of the materials We believe our findings would benefit the deposition of other similar materials on the tapered fiber like other types of TMDs.

ACKNOWLEDGMENTS

This work is partially supported by the Shanghai Yangfan Program (No. 14YF1401600), the State Key Lab Project of Shanghai Jiao Tong University (No. GKZD030033), NSFC (No. 61178007, No. 51302285), the External Cooperation Program of BIC, CAS (No. 181231KYSB20130007). J. W. thanks the National 10000-Talent Program and CAS 100-Talent Program for financial support.

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