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To cite this article: N H Muhamad Apandi *et al* 2021 *J. Phys.: Conf. Ser.* **2075** 012005

Amplitude modulator of Multi-walled Carbon nanotubes/Chitin in the C-band region

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Abstract. In ultrafast all-optical signal processing, the all-optical method is crucial, and all-fiber technique offers a wide range of applications in optical communications. This study investigated the amplitude modulation using multi-walled carbon nanotubes (MWCNTs) embedded into chitin as saturable absorber (SA). The MWCNTs-chitin SA is fabricate using a liquid phase exfoliation method to reduce complexity and produce an excellent material quality. In this paper, an optical amplitude modulator produced a linear region with a regression line of the peak intensity at pump power range from 17.92 mW to 67.92 mW with modulation efficiency of 0.50 dB/mW.

1. Introduction

Optical modulation is a mechanism where data information is load upon the light beam. Modulation is achieved by modifying light beam typically such as direction, amplitude, phase, frequency and polarization state [1]. Due to the recent development of nanotechnology and material science in device fabrication, the modulation speed, modulation range broadening and energy consumption reduction has been improved [2]. 2-dimensional (2D) nanomaterials attract researchers as a promising in acquiring opto-electronic applications since the discovery of graphene in 2004 ago. Some of 2D materials have an excellent optical property like high saturable absorption, quick recovery time, high nonlinearity and broadband absorption thus initiate considerable use in photodetectors, optical modulators and optical transistors [3]. The MWCNTs are essentially rolled graphene, which is composed of carbon atoms that have formed hexagonal networks that eventually form a long cylindrical structure [4]. They possess many advantages in nonlinear optics, high thermal conductivity and high mechanical strength [5-6]. Liu et al. (2013) demonstrated an all-optical modulation by using microfiber graphene at wavelength of 1550 nm with modulation efficiency of 0.002 dB/mW [7]. Ahmad et al. (2019) proposed a heterostructure thin film of molybdenum tungsten disulphide and reduced graphene oxide in polyvinyl alcohol ($MoWS_2$-rGO/PVA) as saturable absorber. The modulation efficiency obtained was 0.30 dB/mW at 1550 nm wavelength [3]. On the other hand, Chong et al. (2016) achieved modulation efficiency of 0.09 nm at wavelength of 1550 nm by integrated optical waveguide with a coating of graphene oxide (GO) [8]. Ahmad et al. (2020) also generated amplitude modulator by employed bismuth telluride (Bi_2Te_3) flakes through mechanical exfoliation. Two values of modulation efficiency acquired were 0.05 dB/mW at pump power range of 0.00 mW to 80.32 mW and 0.81 dB/mW at pump power of 80.32 mW to 98.64 mW, respectively [9].

Through liquid phase exfoliation, SAs from various classes of materials have been fabricated by using two commonly water polymer such as polyvinyl alcohol (PVA) and polyethylene oxide (PEO). In this work, the development of optical modulation utilized MWCNTs embedded in chitin as SA. Chitin is a biopolymer derived from mushrooms [10] was used as an alternative to a man-made polymer. The MWCNTs-chitin were synthesized using liquid exfoliation method due to its simplicity to develop a composite SA. The MWCNTs-chitin SA then integrated into the linear cavity laser in the C-band region.

2. Methodology

The MWCNTs materials were first utilized to fabricate the SA by embedding them in acrylonitrile-butadine-styrene (ABS) 3D printer filament, which can be obtained offline or online; commercially. In this experiment, the diameter and weight of the filament that have been purchased online from 3Dxtech is 1.75 mm and 750 g, respectively. First and foremost, the MWCNTs-ABS printer filament was extruded by utilizing a 3D printer through a nozzle diameter of 0.4 mm at 210 ^{o}C. The main aim was to trim the diameter of the filament to 200 µm. Later, the filament was then weighed for at 25 mg and combined with 1 ml of acetone before being sonicated for 5 minutes to dissolve the ABS. Finally, the MWCNTs-acetone suspension is produced. MWCNTs-chitin composite was prepared by adding the MWCNTs-acetone suspension into a chitin with one to one ratio totalling up to 5 ml to produce a film with thickness around 50 µm for a strong and sturdy film that would be easily peeled off later. The MWCNTs-chitin composite was realized by sonification process for more than one hour. The mixture was then placed into a circular shape plastic petri dish with diameter of 32 mm and 10 mm height. It was then was left to dry in ambient temperature for 36 hours to allow ample time for the solution to dry up and thus generating MWCNTs-chitin film SA.

To generate the amplitude modulation, MWCNTs-chitin SA was further cut into small pieces of ~1 mm^2 × 1 mm^2 and transferred onto a FC/PC fiber end to function as SA. The arrangement of the linear cavity setup used in this experiment was identical to previous work [3] as in Figure 1.

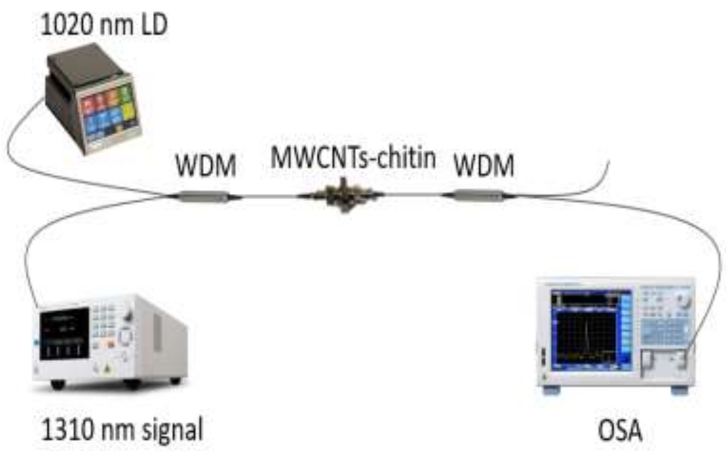

Figure 1. Proposed setup of amplitude modulator for MWCNTs-chitin SA.

3. Results and discussion

Throughout the experiment, the signal light is adjusted at -13.6 dBm or roughly 1.25 mW, resulting in a spectrum peak of -30.12 dBm, as shown in Figure 2. The low signal light guarantees that the 1020 nm pump light induces heat buildup in MWCNTs-chitin SA. The amplitude modulation is evaluated entirely in the spectrum domain to minimize pump light leakage in the WDM, which would impact the modulation results in the time domain if a photodetector and oscilloscope were used. A channel selection or wavelength filter can be added after the second WDM to reduce pumping laser leakage at the output, making the suggested system more feasible in real-world applications. The spectrum is set at 1550 nm at the C-band region. The attenuation trend becomes linear as the pump power is increased further to 17.92 mW, as illustrated in Figure 3 in the linear area between 17.92 mW and 67.92 mW with a modulation efficiency of 0.50 dB/mW.

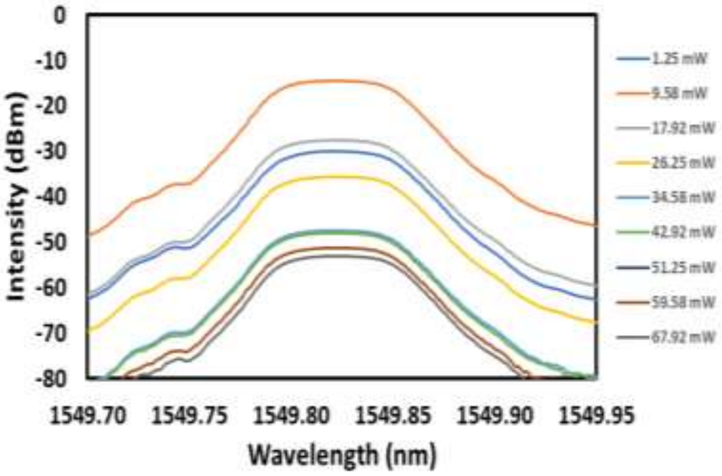

Figure 2. Amplitude modulation of MWCNTs-chitin SA in the optical domain of C-band region.

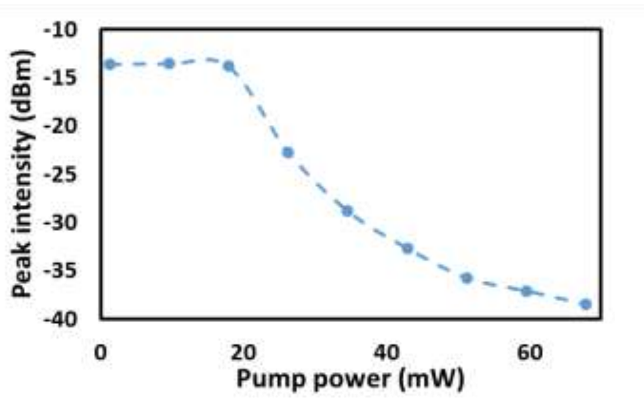

Figure 3. Trend of amplitude modulation of MWCNTs-chitin SA.

4. Conclusion

As a conclusion, we demonstrated MWCNTs-chitin SA has a great potential as an amplitude modulator in the C-band area, with a modulation efficiency of 0.50 dB/mW throughout a pump power range from 17.92 mW to 67.92 mW. Optical modulators play an importance role in numerous fields including optical interconnection, environmental monitoring, biosensing, security applications and medicine. Hence, it is essential to exploit 2D materials for optical modulation to improves the modulation performance such as modulation bandwidth, modulation depth and energy consumption.

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