Demonstration of passive saturable absorber by utilizing MWCNT-ABS filament as starting material

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Abstract. This work demonstrated a stable passively Q-switched laser with the employment MWCNTs dispersed in acrylonitrile butadiene styrene (ABS) resin (MWCNTs-ABS) based filament as passive saturable absorber. The simple fabrication process of the SA is further explained, started from the process of extruding the filament through a 3D printer nozzle at 210 ˚C to reduce the diameter from 1.75 mm to 200 µm. It is then weighed to about 25 mg and mixed with 1 ml acetone before sonicated for 5 minutes to dissolve the ABS. The resultant MWCNTs-acetone suspension is dropped on a glass slide to be characterized using Field-Emission Scanning Electron Microscope (FESEM) and Raman spectroscopy. It is also drop-casted on the end of a fiber ferrule to be integrated in the laser cavity. The proposed work revealed that the laser oscillated at about 1558 nm with threshold input pump power of 22.54 mW and maximum input pump power of 108.8 mW. The increase in pump power resulted in the increase in repetition rate where the pulse train increases from 8.96 kHz to 39.34 kHz while the pulse width decreases from 33.58 µs to 5.14 µs. The generated pulsed laser yields a maximum of 1.01 mW and 5.53 nJ of peak power and pulse energy respectively. The signal-to-noise ratio of 40 dB indicates that the generated pulse is stable.

1. Introduction

The Multiwalled carbon nanotubes (MWCNTs) are basically rolled up graphene, made up of carbon atoms that formed hexagonal networks that eventually build up a long cylindrical structure [1]. It possesses high thermal conductivity [2] and high mechanical strength [3] offering excellent features of ultrafast laser development. It is seen and proved to be a good candidate for saturable absorber (SA). It is an excellent choice for SA integration as it can easily be employed into various fibre configurations while maintaining, an alignment free and all fiber format [4].

On another note, three-dimensional (3D) printing technology since its first invention in the 1980s has been commonly used by companies for the production of conceptual prototypes upon producing the products in mass quantities [5-6]. The printer works by depositing a material such as plastic or metal layer by layer to produce 3 dimensional objects, following the instruction set from the digital designs from computer aided design files (CAD). The science behind the material used for 3D printing is as crucial to that of the 3D printer technology itself. Companies often used pure plastic such as acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) as 3D printer filament but the incorporation of such material with another can give better ink performance [7].

Due to the interesting properties of carbon nanotubes (CNTs) which are mechanically strong, conductive and heat resistance [8], MWCNTs is incorporated with a plastic component, ABS to produce a 3D printer filament. Since MWCNTs have structural defects, the interaction with the polymers is rather strong. The 3D printer filament used in the study is easily obtainable from 3Dxtech. Such printer filament is more focused on industrial usage spanning from automobile to semiconductor industries which often requires strong, conductive and light-weight material in their works. The founder of 3Dxtech [9] also believe that MWCNTs-ABS printer filament can be used in hard drives due to its conductive properties, to replace traditional material, carbon black, with the advantage of a cleaner and more efficient conductivity.

Normally, MWCNTs powder or sheets are used as starting material for SA fabrication. Mechanical exfoliation, metal supported growth, chemical vapour deposition (CVD), and liquid phase exfoliation (LPE) are among the many methods used to realize the SA. Chemically modified graphene from mechanical exfoliation and metal supported growth provide better electrical and structural robustness but the process is rather costly, time consuming, and yield low end material [10-11]. For larger scale and lower cost fabrication, the focus moved towards CVD techniques which involve the process of depositing gaseous reactants to the substrate. However, the even dispersion of the MWCNTs is typically hard to be controlled and maintained. The LPE of MWCNTs is another example of fabrication method there is. The process usually involves three steps, the first being the dispersion of MWCNTs in a liquid medium, second being exfoliation of the dispersed material by using ultrasonication and the last step is the purification process. LPE route requires the nanomaterial to undergo several processes including ultrasonic to disperse the nanomaterials, centrifugation to remove any undispersed suspension and then mix with a host polymer. The use of the commercially available MWCNT-ABS 3D printer filament as the starting material in fabricating the saturable absorber (SA) in this work will demonstrate a simple and timesaving fabrication procedures involved, along with the fabricated SA's performance in pulse laser generation.

2. Material Preparation

The fabrication of the MWCNTs slurry used in the study was started by using MWCNTs in acrylonitrile-butadiene-styrene (ABS) 3D printer filament that is commercially available offline or online. The one used in the study is obtained online from 3Dxtech. When received, the filament diameter and weight is 1.75 mm and 750 g, respectively. The first step to the fabrication of the SA is by extruding the MWCNTs-ABS printer filament by using a 3D printer through its nozzle diameter of diameter 0.4 mm at 210°C. This is to reduce the filament's diameter to 200 µm. We then weighed the filament to about 25 mg to be mixed with 1 ml of acetone before it is sonicated for 5 minutes to dissolve the ABS. The MWCNTs-acetone suspension is finally produced. The suspension is dropped casted on the end of a fiber ferrule to later be integrated in the laser cavity. Another portion is dropped on a glass slide for characterization purposes. When dropped, the acetone on the suspension will evaporate leaving only the MWCNTs slurry. The fabricated MWCNTs slurry is investigated by using Field-Emission Scanning Electron Microscope (FESEM). Figure 1 shows the FESEM image of the MWCNTs slurry with discerning bundle of MWCNTs. The peak shift of the slurry is investigated using the Raman spectroscopy performed using LabRAM HR Evolution. The Raman shift of the MWCNTs slurry is shown in Figure 2 with D-band, G-band and G'-

band at 1346 cm^{-1}, 1574cm^{-1} and 2694cm^{-1}, respectively. The measured insertion loss is approximately 4.5 dB.

3. Material Characterization

The morphology of the fabricated MWCNTs slurry is investigated by using Field-Emission Scanning Electron Microscope (FESEM). Figure 1 shows the FESEM image of the MWCNTs slurry with discerning bundle of MWCNTs. The peak shift of the slurry is investigated using the Raman spectroscopy performed using LabRAM HR Evolution. The Raman shift of the MWCNTs slurry is shown in Figure 2 with D-band, G-band and G'-band at 1346 cm^{-1}, 1574cm^{-1} and 2694cm^{-1}, respectively. The measured insertion loss is approximately 4.5 dB.

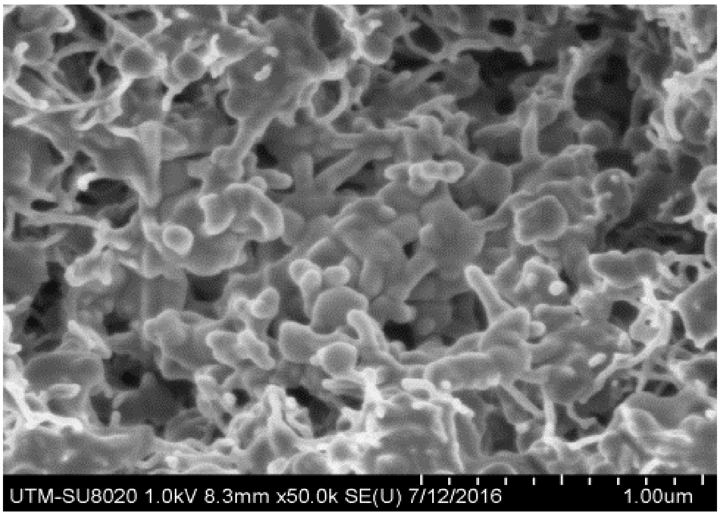

Figure 1. FESEM image of MWCNTs slurry.

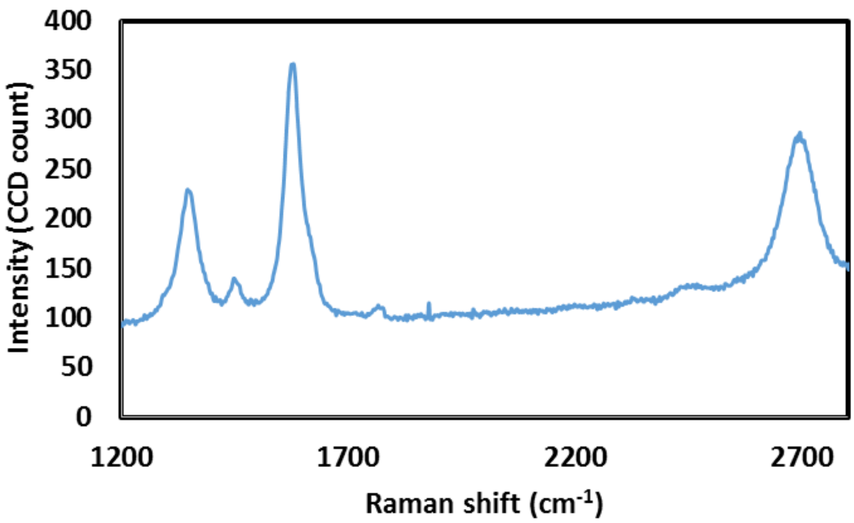

Figure 2. Raman spectroscopy of MWCNTs slurry.

4. Experimental Setup

The Figure 3 below shows the experimental setup of the passively Q-switched EDFL. The ring cavity of the overall setup consisted of a 1 m long Erbium-doped fiber (EDF) which is used as the gain medium, a 980/1550 nm wavelength division multiplexer (WDM), an isolator, the newly fabricated MWCNTs slurry as SA, and an 80/20 output coupler. The core and cladding diameter of the EDF is 8 μm and 125 μm respectively. The numerical aperture of the EDF is 0.16 and has Erbium ion absorptions of 45 dB/m at 1480 nm and 80 dB/m at 1530nm. The EDF was pumped by a 980 nm laser diode via the WDM. An isolator is incorporated in the laser cavity to ensure no back propagation of the oscillating laser. The output of the laser was tapped from the cavity through a 80/20 coupler while keeping 80% of the light to oscillate in the ring cavity. An optical spectrum analyser (OSA) with a spectral resolution of 0.05 nm is used to inspect the spectrum of the EDFL, whereas the oscilloscope was used to observe the output pulse train via a 460 kHz bandwidth photo-detector.

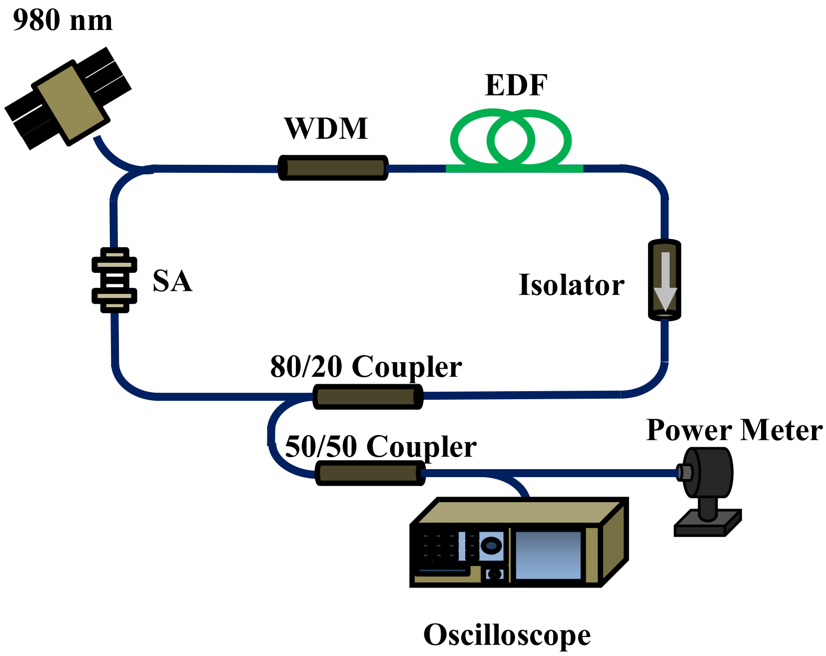

Figure 3. Experimental setup of the proposed passively Q-switched EDFL with MWCNTs slurries based SA.

5. Results and Discussions

The proposed EDFL started to lase with passively Q-switched mode at 22.54 mW of input pump power. The threshold pump power is notably lower than that reported in [1, 12-13] using similar two-dimensional (2D) materials. The low pump power threshold may be caused by the low saturation intensity properties of the material itself. Figure 4 shows the optical spectrum analyser trace at maximum input pump power of 108.8 mW with two peaks occurring at 1558.0 nm and 1558.4 nm. The observed peaks are due to mode competition of the gain medium used in this work. Figure 5 shows the oscilloscope trace of the Q-switched pulse at maximum input pump power of 108.8 mW with corresponding repetition rate of 39.34 kHz with the separation of adjacent pulse is around 24.5 μs. No distinct amplitude modulation is observed, indicating the stability of each Q-switched envelope. The single pulse envelope of the shortest pulse width at maximum input power of 5.14 μs is as shown in Figure 6.

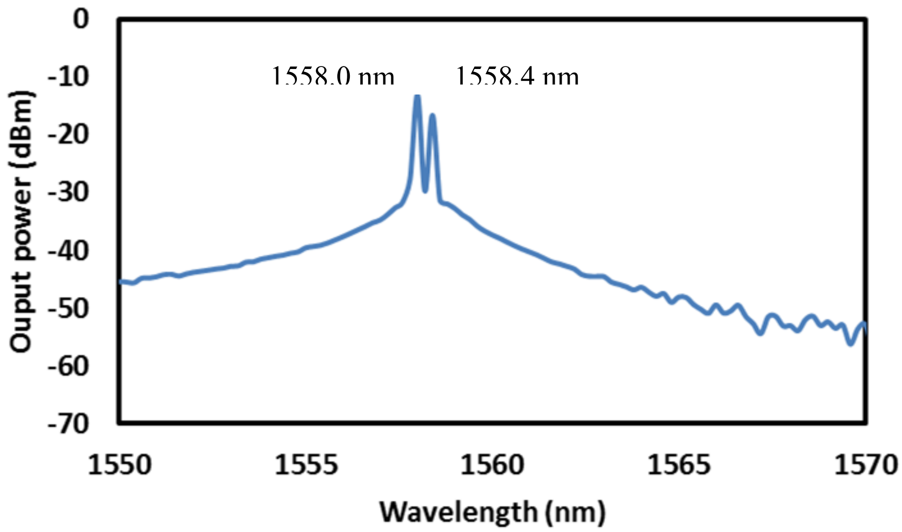

Figure 4. OSA trace at at maximum input power of 108.8 mW.

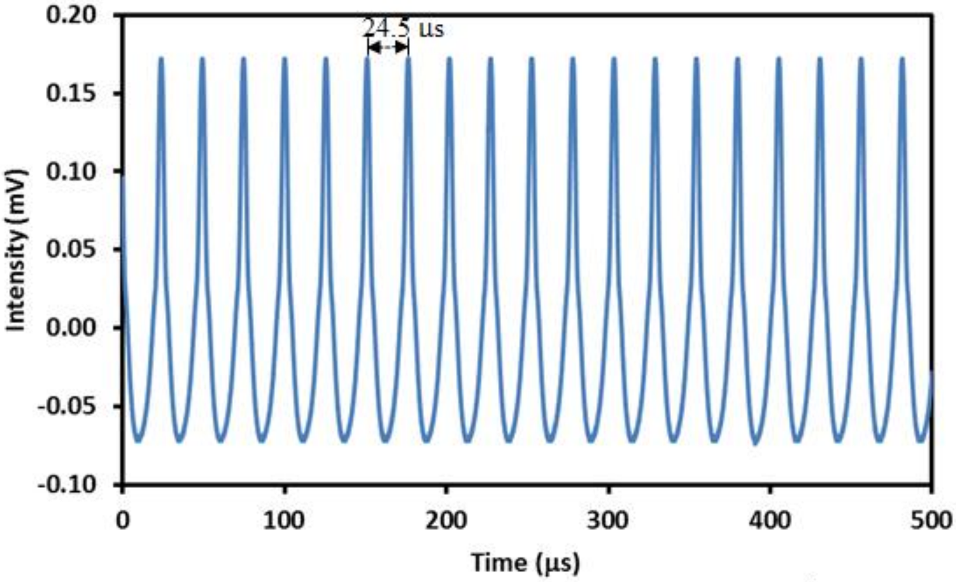

Figure 5. Pulse train of 39.34 kHz at maximum input power.

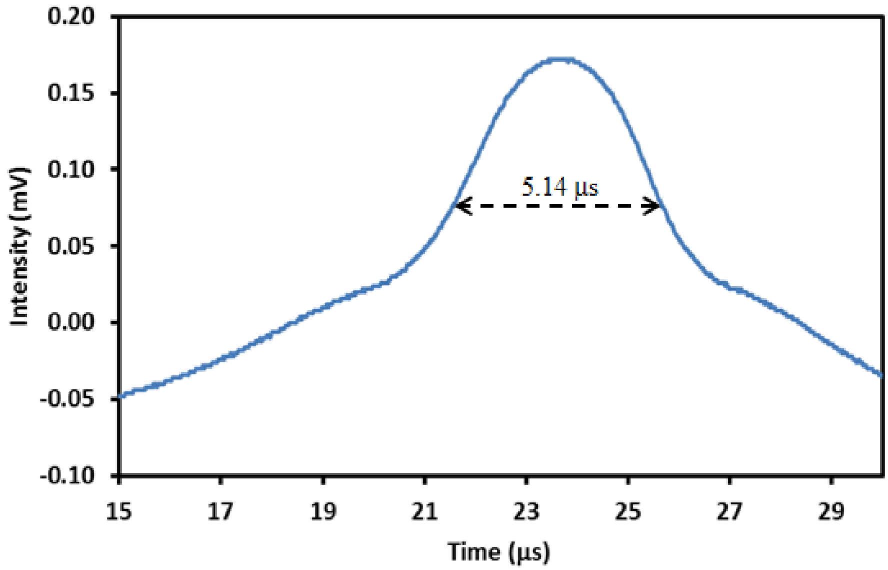

Figure 6. Single pulse envelope of the shortest pulse width of 5.14 µs.

The dynamics of the pulsed laser is investigated by tuning the pump power. As seen in Figure 7, increasing the pump power from 22.54 mW to 108.8 mW makes the repetition rate higher and the pulse width narrower. As function of the pump power, the repetition rate increases from 8.96 kHz to 39.34 kHz while the pulse width reduces from 33.58 µs to 5.14 µs, a trend typical of a passively Q-switched pulsed laser [14-16]. This is caused by the shorter time for the inversion number of the gain medium to reach the threshold due to the increasing pump power.

Figure 8 shows the peak power and pulse energy as a function of the input pump power, both increases with the increasing pump power. By increasing from threshold to maximum input pump power, the peak power and pulse energy monotonically increases yielding a maximum of 1.01 mW and 5.53 nJ, respectively with an average output power of around 0.2 mW.

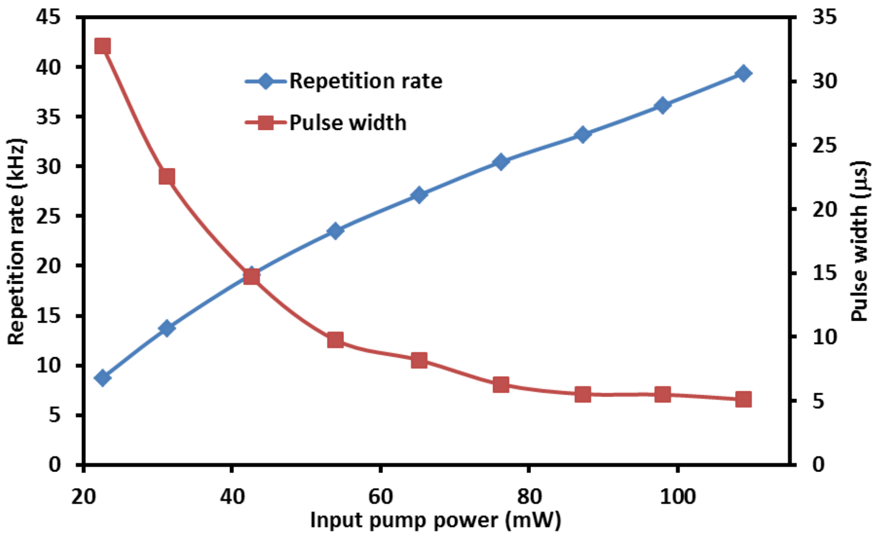

Figure 7. Repetition rate and pulse width as a function to input pump powers.

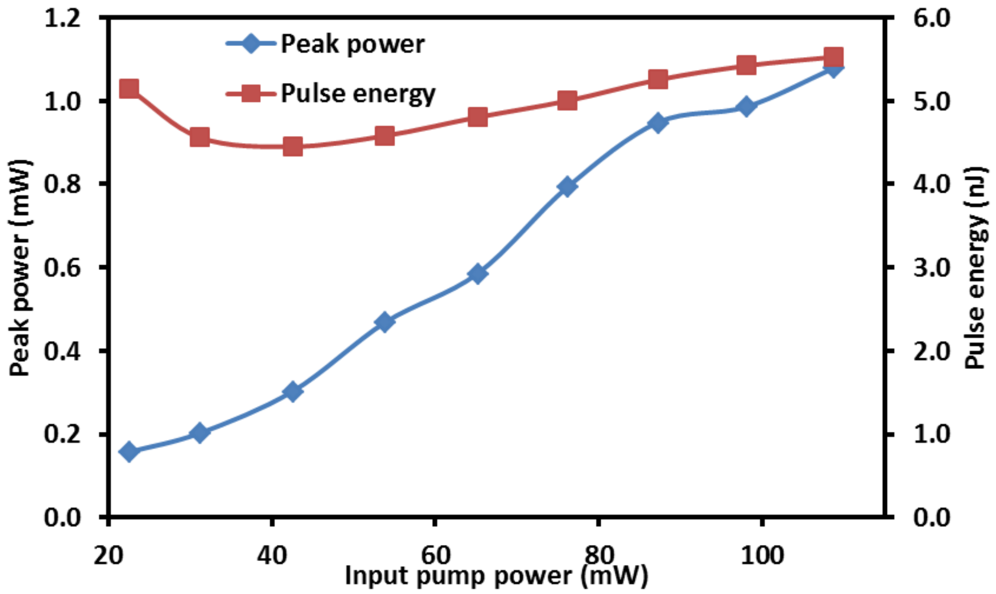

Figure 8. Instantaneous peak power and pulse energy as a function to input pump powers.

Radio frequency spectrum analyser (RFSA) is used to measure the signal-to-noise ratio (SNR) of the generated pulse. The value of the SNR is often an indicative of the pulse stability level. Figure 9 shows the recorded RFSA measurement at maximum input pump power of 108.8 mW. The first beat node at 39.34 kHz is around 40 dB and no peak occurs other than the harmonics of fundamental frequency, showing the stability of the pulse.

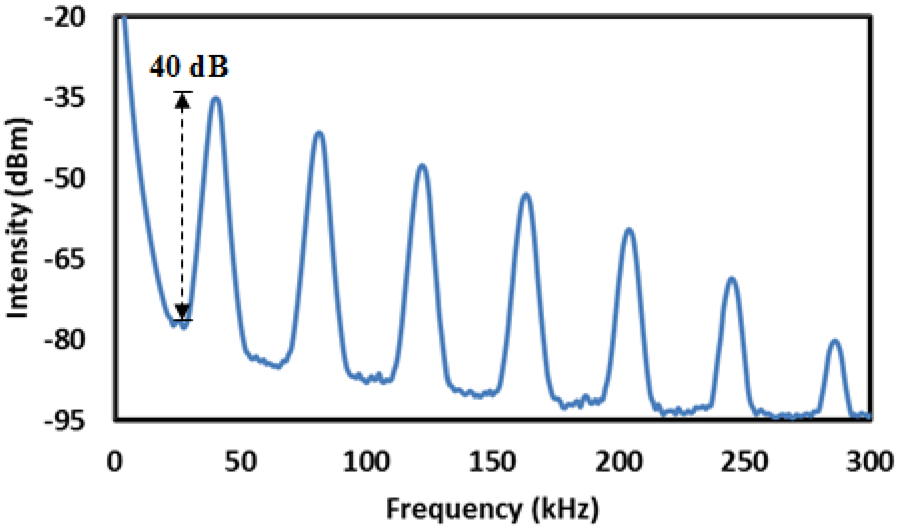

Figure 9. RFSA measurement of SNR at 108.8 mW.

6. Conclusion

To conclude, the proposed passively Q-switched EDFL employing the saturable absorber based on MWCNT-ABS printer filament was successfully demonstrated. The proposed work revealed lower threshold pump power as compared to previously reported works using SA based on MWCNT as starting material. The fabrication process is relatively simpler, involving three simple and timesaving steps; extruding the filament, dilution of the material using acetone and drop casting of the MWCNTs slurry.

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