Feasibility of CNT based Sensor for UV Detection in Combustion Process for Aerospace Applications

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Abstract

Measurement of spectrum of Ultra Violet (UV) radiation emission is used in the monitoring of any combustion process. The development of miniaturized Carbon Nano Tube (CNT) based sensor has been proposed in this work for the detection of UV radiation in order to monitor the process of combustion in an aircraft engine. In the current work, nearly-vertically aligned CNTs were synthesized on Silicon substrate using a Radio Frequency based Plasma Enhanced Chemical Vapour Deposition (RF-PECVD). The synthesized CNTs were subjected to wire bonding at 4 ends of the sensor and later deposited with Parylene which acted as a transparent, protective coating which transmitted the UV radiation completely as well protected the CNTs from peel-off. In order to test the feasibility of the proposed sensor, only a mono wavelength UV LED of 365 nm was used as an emission source. The UV emission source was calibrated for its peak power using a radiometer. The distance of the UV source was varied to simulate the difference in intensity of UV emission source power. A 7.5 digit multi meter with 4 probe measurement system was used to measure the resistance of the CNT based sensor before and after UV emission. The average resistance before without UV sensing was around 60-65 kΩ. A decrease in resistance of about 5-7 kΩ in the sensor was noticed when UV source was switched on. The hysteresis value of the sensor was less than ± 0.05 kΩ.

Keywords: CNT sensor, UV sensor, PECVD, Low Hysteresis.

1. INTRODUCTION

Fuel efficiency of aircraft engines signify not only the efficiency of the engine but also convey the performance characteristics of the jet engine. An efficient fuel combustion process involves the intake of air, high compression and timed spray of fuel into the highly compressed volatile air intake. This ignites the fuel to supply energy for the aircraft. A complete combustion process would efficiently emit UV radiation and monitoring this is extremely essential to understand the health condition of the jet engine. This research work deals with the experimental development of a UV sensor and assessing the feasibility of the sensor to be used in aerospace applications

Prior literature has already stated the effect of UV excitation on electrical properties of CNTs. Most of the literature has been with regard to ultra-fast detectors and gas sensors. Ambrosio and Aramo have worked on the development of UV camera which is required for the detection of UV using CNTs based p-n junction diode [1]. Najeeb et al., have investigated the development of UV photo detector based on CNT PEDOT-PSS composites, where single wall CNTs have been utilized [2]. Chen et. al., have irradiated CNT based TFTs with UV for use in gas sensor and recorded a change in resistance of about 5kΩ after UV excitation [3]. Junya et. al.,[4] have reported extremely slow response of electrical characteristics when ZnO nanowires were exposed to UV radiation. Later on the authors [5] changed ZnO to CNTs aand added Pd catalyst and found that with addition of H_2 gas response time recovery could be achieved faster with UV irradiation. In this case, a 365 nm UV light source was used similar to the current experimentation as mentioned in this article. Wang et. al., [6] have reviewed various literature and have reported the decrease in response time and change in conductance of CNTs to detect nitrogen gas in the presence of UV illumination. Lin et. al., [7] have deposited ZnO on CNTs using Atomic Layer Deposition (ALD) technique to configure CNTs to behave as p and n –type photo detectors when irradiated with a UV light source. Shao et. al., [8] have deposited ZnO on MW-CNTs using ALD technique and excited the film composite with a UV source having a wavelength of 375 nm. The authors have recorded a response time to detect UV between 29 and 33 ms. From this it can be inferred that there is much scope to extend CNTs to be used as UV detection sensors for various applications. An attempt has been made in this study to understand the feasibility of CNTs to be implemented to detect UV to monitor combustion in aircraft engines.

2. EXPERIMENTATION

A few similar sized silicon wafer pieces of approximate size 20 x 20 mm was selected, cleaned thoroughly and placed in a Physical Vapour Deposition system. A seed layer was required to be coated on the silicon wafer in order to synthesize CNT. Nickel was sputtered for a thickness of 5 nm using an Elettrorava PVD system. To ensure the uniformity of coating, the substrate was under rotation at 5 rpm. After sputtering of nickel, the silicon wafer was placed in a PECVD chamber. A Roth & Rau HBS 500 model RFPECVD was used for deposition. The sputtered nickel was initially nucleated to for nickel islands for a period of 10 min using hydrogen gas. The flow rate of hydrogen was maintained at 120 sccm. Later, acetylene gas was introduced in the chamber. The ratio of acetylene to hydrogen flow rate was maintained at a ratio of 1:8. The deposition was maintained for a time period of 30 min.

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The synthesized CNTs were then charcterised using Scanning Electron Microscopy (SEM) and Raman Spectroscopy for its quality. After characterization, the deposited CNTs were subjected for preparation for UV sensor. The silicon wafers deposited with CNTs were subjected to wire bonding using conductive silver epoxy paste. After the leads were drawn, a transparent di-electric layer of parylene was coated specifically over the CNT surface on the wafer to improve the adhesion and bonding of CNTs over the silicon wafer and ensured there was no peel off of the CNT film. The entire sensor head was then sandwiched between two glass slides for durability during the testing and measurement phase. The image of the prepared sensor head is shown in figures 4-7.

3. RESULTS AND DISCUSSIONS

3.1 Scanning Electron Microscopy

SEM is used to observe the morphology of the films at nano scale. The morphology of annealing of sputtered Nickel films and measuring the island size was performed using SEM. A typical nucleated image is as shown in fig. 1. The size of the islands formed range between 5-40 nm.

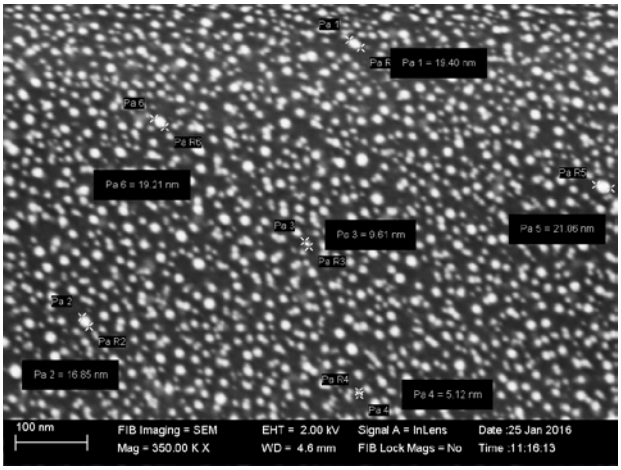


Fig. 1. SEM image of nucleated Ni catalyst

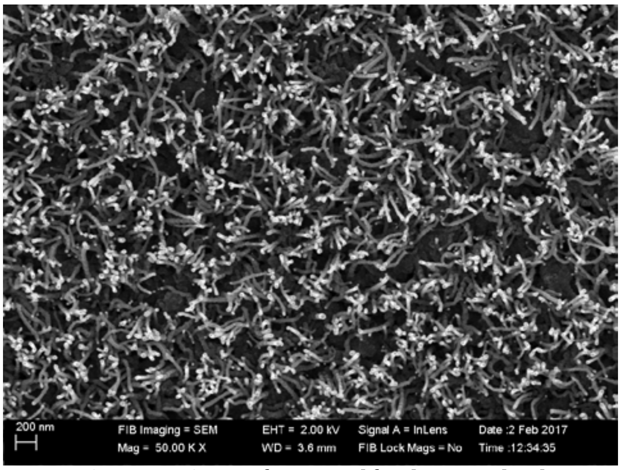


Fig. 2. SEM image of CNT used for the sensor head

After nucleation, the sample was subjected to deposition of CNTs. It is known that the diameters of the CNTs are directly proportional to the thickness of the catalyst. The deposited CNTs were nearly vertically aligned and the diameter of the tubes varied between 25 – 40 nm as given in fig. 2.

3.2 Raman Spectroscopy

Raman spectroscopy gives an estimate regarding the quality of CNT. Fig. 3 gives the estimate of Raman spectra observed in the CNT sample.

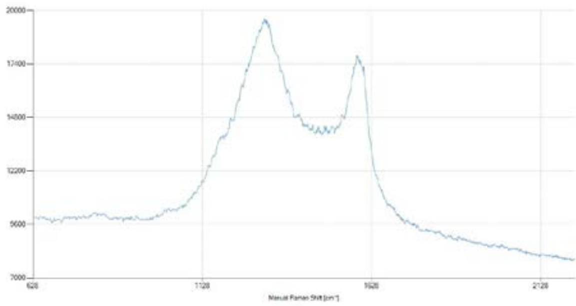


Fig. 3. Raman spectra of the CNT

From the Raman spectra it was observed that the intensity count of 19800 was measured at D-peak having 1325 cm^{-1} as Raman shift and intensity count 17600 was measured at G-Peak having 1590 cm^{-1} as Raman shift. From the peaks it can be observed that the CNT is of good quality with very low amorphous carbon content. The Raman spectra results corroborate with the SEM results as shown in fig. 3.

3.2 Electrical Characterization

After preparation of the CNT samples to the required format as shown in fig. 1, the samples were subjected to resistance measurements. The prepared CNT sensor head was measured for its resistance using a 7½ digit 4 probe Keysight multimeter. The excitation for UV was provided by a Hamamatsu UV LED having a mono wavelength of 365 nm. The intensity of UV LED was measured to be 950 mW/cm^2 using an Omnicure radiometer. The UV LED light source was maintained at a distance of 32 mm from the CNT deposited silicon wafer sample during all measurements. Repeated measurements were recorded using the aforementioned multimeter at an interval of 45 sec during the UV on or off state. Three samples were selected. The variation in the size of the sample was within ±2 mm. This has resulted in variation in resistance. The lead nomenclature is as given in fig 4.

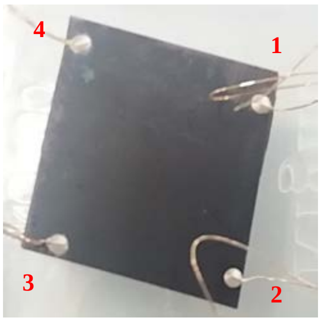
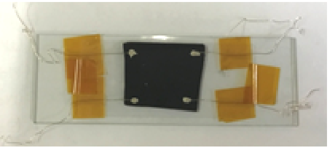
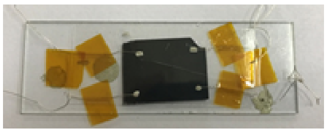
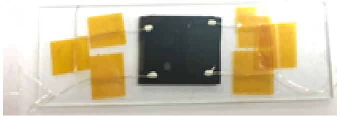


Fig. 4. Lead nomenclature on the sample

From fig. 4 it can be noted that values measured between leads 2-4 and 1-3 will vary considerably than other lead combination as distance increases due to diagonal measurements. The repeatability of the sensor heads have also been tested using three different samples.

Table 1: Resistance values for all samples between 4 leads

	Sample 1		Sample 2		Sample 3	
Lead	**W/o UV (kΩ)**	**UV (kΩ)**	**W/o UV (kΩ)**	**UV (kΩ)**	**W/o UV (kΩ)**	**UV (kΩ)**
1-2	65.26	57.99	66.4	58.2	57.29	50.1
1-3	71.9	65.84	69.5	59.7	67.8	59.7
1-4	64.3	58.9	63.4	55.5	64.6	56.6
2-3	69.5	62	72.2	66.2	60.2	55.6
2-4	66.4	59.52	68.6	61.7	61	55.4
3-4	65.3	60	62.4	58.4	60.3	55.8
	 **Fig. 5. Sample 1**		 **Fig. 6. Sample 2**			

From table 1, it can be observed that after excitation with UV light the resistance values for non-diagonal regions are quite repeatable with an average about 58 kΩ.

The following observations were noted during the measurements:
• Hysteresis value of the sensor head was within ±0.05 kΩ.
• Response time of the sensor head is extremely slow and is in the order of a few seconds.
• The difference of resistance without UV and with UV light is between 5-7 kΩ and can be improved with the automation of sensor fabrication.

4. CONCLUSIONS

4.1 Development of CNT

Synthesis of quality CNT is extremely essential for improving UV sensitivity of CNTs. Any amorphous carbon content will decrease the sensitivity. Hydrocarbon (HC) to dilution gas ratio is required to be maintained at 1:8. It was observed that higher the HC to Dilution gas ratio yields longer CNTs, however, the higher gas ratios have poor adhesion as seen in previous experiments that has not been reported here. The sensors that have been developed from the previous experiments have higher change in resistance from sample to sample based on the uniformity and poor adhesion of the CNT coating. From SEM images it was observed that the average CNT diameter ranged between 25-40 nm. The diameter of the CNT depends on the thickness of the film. Raman spectroscopy has determined a count of about 19800 at 1325 cm^{-1} which indicates better quality of CNTs. The quality of CNTs determines the repeatability of the sensor performance.

4.2 Electrical Characterization of CNT sensor head

From electrical characterization after exciting with monochromatic UV source of 365 nm it is observed that the CNTs are UV photosensitive. The difference in resistance between on and off state of UV light is about 5 kΩ. The change in resistance reported in this work has been for a reading measured after 15 seconds of stabilization of resistance value. Hysteresis has been found to be extremely low of about ±0.05 kΩ.

These experiments confirm the UV photo sensitivity of CNT and could be used as sensor head when packaged with signal amplification and conditioning unit. The following section discusses the improvement of UV sensor head which could be used in the monitoring the combustion process in an aircraft engine.

5. FUTURE WORK

From the experiments it could be concluded that CNT based sensors could be used for detection of UV radiation. The amount of UV sensing requires to be calibrated using a standard UV source. ASIC and other related amplification circuitry requires to be built around the sensor head to ensure that the sensor becomes compact. To improve the response time within few milli seconds and to increase the signal to noise ratio, the size of the sensor could be diced within 2 x 2 mm. Also, the performance characteristics could be improved when the process is on a wafer scale. An entire wafer could be deposited with CNT and it requires being dry diced using laser. This would ensure that the wafer will not cleave as per the crystal orientation and repeatable results can be achieved. Such packaged sensors with thermal protection could be used in the combustion region of aircraft engines to monitor the combustion efficiency of fuel.

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