Supplementary Information

Growth of dense CNT on the multilayer graphene film by the microwave plasma enhanced chemical vapor deposition technique and their field emission properties

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1. Details of Deposition system

We have used an indigenously built MW PECVD system. The photograph of the deposition system is shown in Figure 1. Microwave generators are designed to provide stable and controlled microwave power and are found in two configurations namely integrated and modular microwave system. We have a modular system which consists of the separate building components, namely power supply, magnetron head, cable assembly, etc. It consists of a high voltage transformer, rectifier diode, capacitor, magnetron, waveguide for the process chamber. The high voltage transformer has typically a secondary of around 2000 VRMS at 25 Ampere, more or less depending on the power rating of the magnetron. There is also a low voltage winding for the Magnetron filament (3.3 V at 10 A is typical). It is the largest and heaviest component of the generator. There is a pair of quick connect terminals for the AC input, a pair of leads for the magnetron filament and a single connection for the HV output.

1.1 Rectifier

It is usually rated 12000 to 15000 peak reverse voltage (PRV) at around 5 A. Most commonly, it is in rectangular or cylindrical shape and about 5 inches long with the wire leads. In this generator, a box bolted rectifier is used. One end of it is electrically connected to the chassis.

1.2 Capacitor

It is 0.65 to 1.2 μF at a working voltage of around 2000 V A. C.. It is to be noted that this use of working voltage may be deceiving as the actual voltage on the capacitor may exceed this

value during operation. The capacitor is a metal cased with the quick connect terminals on top (one end).

1.3 Magnetron

Magnetron consists of a vacuum tube, electrons are emitted from a heating electrode (barium oxide coated tungsten) and attracted towards the anode which has relatively the positive potential. A magnetic field aligned parallel to the electrode is applied to provide electrons a spiral motion due to the magnetic force perpendicular to their motion. Synchronize radiation causes electrons to radiate microwaves. The frequency of microwave depends upon the size of the cavity. We are using magnetron (National Electronics Inc, USA, model YJ 1540) operating at 2.45 GHz of rating 1.2 KW.

1.4 Isolator/Circulator

A circulator is three port device utilizing ferrite technologies to selectively direct microwave energy to the specific port. An isolator protects microwave generator from the reflected microwave energy and provides the magnetron a matched load for the generation of efficient microwave energy. Isolator (model PHILIPS, 2722 163 02101) with inbuilt detector (DD 1212) has been used in this system.

1.5 Three stub tuners

Stub tuners are the mechanical waveguide component used for matching the impedance of the load and source to reduce the reflected microwave energy and to deliver maximum power to the load. By adjusting these metal stubs, microwave energy is tuned to give the minimum reflected power. The manually controlled three-stub tuner made by the National Electronics Inc, USA (model WR 340 tuner) is used in this system.

1.6 Waveguide

Waveguide size depends on the frequency and power of the microwave. In the present system, the waveguides (Al) having the dimensions (86.4 x 43.2 mm, wall thickness ~ 2 mm) is used (make: National Electronics Inc, USA, model WR 340 HBBSB).

1.7 Deposition chamber

The stainless steel chamber is made by M/s New Poona Industries, Pune (India). It has two viewing ports at 45º and two ports for feed through, three pressure gauges. Substrate holder is placed on the molybdenum heater. Substrate temperature of 900 ºC can be achieved with the help of resistive heating. The chamber is cooled with the help of water channeled copper tubes welded

to the deposition chamber. A turbo-molecular pump (PFEIFFER VACUUM GmbH, Germany, model TMU 260 PC, DN 100CF-F, 2P), with a pumping speed of 260 l/s is used to evacuate the process chamber. This is backed by a rotary pump (Make, PFEIFFER VACUUM GmbH, Germany, model OIF5, P2751, 40205). High pressure is controlled with the help of a throttle valve. Gas delivery is achieved using a system consisting of three mass flow controllers (Sevenstar Electronics Mass flow meter) and pneumatic valves supplying the reaction gases into a mixing rail and ultimately to the system. This information is provided in the supplementary information in the revised manuscript.

Fig. 1 Photograph of Microwave PECVD system

Fig. 2 MLG on copper before and after plasma treatment.

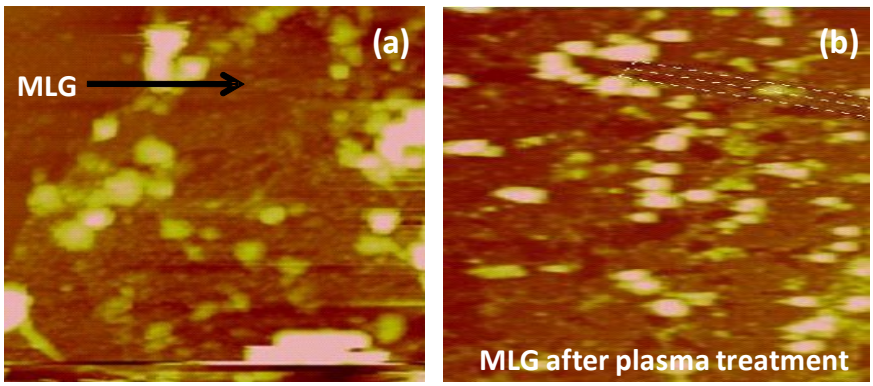

Fig. 3 AFM image of Ni nanoparticles.