Development of Graphene-Based Field Emitter for THz Device Application

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Abstract

Development of graphene-based field emitter for application in THZ VEDs have been the main objective. Modified Hummers method, Vacuum Filtration and thermal annealing technique has been adopted to develop a ~ 5μm film. The characterization results using SEM, Raman and XRD have also been discussed herewith.

Introduction

Recently, the development of a compact terahertz (THz) Vacuum Electron Devices (VEDs) for application like communication, remote sensing, security, medical imaging, etc has gained immense pace. When compared to the existing THz solid state devices, the VEDs offer high energy conversion efficiency, thermal robustness and radiation hardness [1]. One of the critical challenges in the development of the THz VEDs is the requirement of very high current density electron emitters. Though, most of the effort in this area has been directed towards the development of scandate cathodes, capable of delivering current density in excess of 100 A/cm2, still a higher current density, of the order of 1000 A/cm2, would be required at frequencies > 200 GHz [2].

Till date, in almost all the high-power VEDs employ the thermionic cathode, however its use could be limited at high frequencies as the device size scales down with frequency. In that case, the field emission cathodes will be the best possible candidate to cater to such high current density needs. The field emitters are generally characterized with instant turn-on, high current density, lower power dissipation and Micro-Nano fabrication technology. In principle, these cathodes will be very useful in realizing the high frequency compact and light-weight VEDs however, the reliability and the life are yet to be established. In the past, numerous dedicated efforts have been made to develop the high current density field emitter arrays. Arrays of cathodes with 107 tips /cm2 could be produced, using micro fabrication technology, and the emission densities of 1000 A/cm2 could be achieved from 10000 tips [3]. Arrays of carbon fibre coated with CsI have been reported to yield 50 A/cm2 over one million pulses at 165 kV [4]. The use of the FEAs has been limited for two reasons: (a) the surface of the FEA tip is highly dynamic as adsorption of the ambient gases changes the work function of the surface, and (b) the ion back bombardment changes the radius of curvature of the tip during the operation. Recently, graphene-based field emitters have attracted immense interest due to its high aspect ratio (thickness to lateral size ratio), high carrier density, the larger carrier mobility, excellent electrical and thermal conductivity and stability. Graphene, a single /multiple layer (< 10 layers) of carbon sheets, can be synthesized using various methods such as chemical vapor deposition, chemical exfoliation, electrophoretic deposition, screen-printing and chemical techniques. The criticality of the film is the it should able to bear the thermal load due to the joule heating caused by the electron drift and high machinal strength to hold the film firmly at such high temperature operation.

GO film Synthesis

For the synthesis of graphene film suitable for very high current density applications, large yield is required and hence the choice of synthesis is modified Hummers method [5]. The synthesis flowchart has been depicted in the fig. 1.

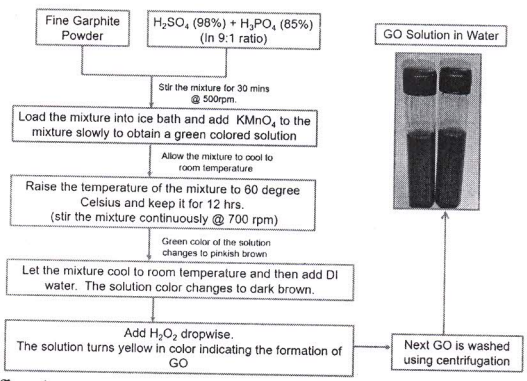

Fig. 1. Modified Hummers Method for GO synthesis.

GO film was prepared using Vacuum filtration technique [6] as shown in fig. 2 (a). The thickness of the film depends on the concentration of the GO solution. 0.45μm PTFE membrane was used as the filter paper on which the film was obtained. The film was the left overnight for drying in a vacuum oven at 60 ^{0}C. The GO film was then fished out by dissolving the PTFE membrane in acetone. The film was prepared out of 20 ml GO solution in water (1mg/ml) as shown in fig. 2 (b). The GO film could not be used directly for high current density application as due to the high oxygen content, the conductivity is very low. So, the film was further hydrogen fired 1300 ^{0}C for 10 mins. The dark brown GO film turns to shin black rGO film after hydrogen reduction.