ELECTRON FIELD EMISSION FROM AMORPHOUS CARBON FILMS

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Abstract

Amorphous carbon films have attracted considerable attention due to their possible application as potential field emission cathode materials.We have studied the electron field emission from the amorphous carbon films prepared at different temperatures by pyrolysis in an inert atmosphere. The prepared carbon films have been cleaned in acetone and electron field emission experiment was done at a pressure of 2×10^{-6}torr.By fitting the experimentally observed data with Fowller-Nordheim current versus voltage equation we have found the field emission to be an electron tunneling phenomena.

Introduction

Currently, there has been an increased interest in electron field emission for potential flat panel display (FPD) technology[1-3]. Electron field emission studies from amorphous carbon films [4-5] diamond films [6-7], diamond like carbon films [8-9] and carbon nanotubes [10-11] have been performed because of their novel properties such as negative electron affinity [12] and low work function [13]. In order to use as cathodes in flat panel display there are three important requirements. The first one is the high emission current density at a reasonably low applied electric field. The second is the densification of emission area. The third is the low synthesis temperature so that low cost substrates can be used. For a-Carbon and Carbon based materials the field emission display to be feasible from an industrial perspective, it should be possible to grow them over large areas, at high deposition rates and at low temperatures. The electron field emission properties of amorphous carbon based materials have attracted a great deal of attention with regard to their potential use as cold cathodes in field emission displays due to their ability to emit electron from nominally flat, or intrinsically geometrically enhanced films at low electric fields.

Experimental

The amorphous conducting carbon is prepared by pyrolysis assisted chemical vapor deposition (CVD). The precursor taken in this case is maleic anhydride ($C_4H_2O_3$). The pyrolysis assisted chemical vapor deposition is carried out in a standard double furnace setup in a fused silica tube placed inside, whose length

spanning both the furnaces as shown in Fig.1. The furnaces have non-uniform winding so that an approximately isothermal region along the tube is achieved. The furnaces were controlled by PID temperature controllers. The precursor material is placed at one end of the tube which, is kept in the hot zone of furnace A (Zone A). The substrates are kept inside the quartz tube in the hot zone for furnace B (Zone B). The substrates in zone B are heated first to the desired temperature say about 700^{o}C, then the zone A is heated so that the precursor vaporizes and moves into zone B. The vapors entering hot zone B thermally fragment into highly reactive species. These reactive vapors when coming in contact with the preheated substrates get pyrolysed forming amorphous films. The conducting amorphous carbon film has got few of the general features. The morphology is such that the films are silvery black in color, shining and has metallic luster. The thickness of the film is in the order of 1μm to 40μm depending on the amount of precursor used and the deposition time. The composition found out by elemental and RBS analysis is 99.5 % carbon and 0.5 % hydrogen. The amorphous nature of the films and powders were characterized by XRD, which shows the broad hump centered around ~ 22 degrees confirming the amorphous nature of the carbon[14]. This amorphous nature is reflected in neutron scattering analysis as well. Raman spectral analysis also suggests the presence of disordered and polymeric modes present [15]. Samples prepared at 700^{o}C, 800^{o}C and 900^{o}C temperature have similar morphology with no structural ordering in the film.

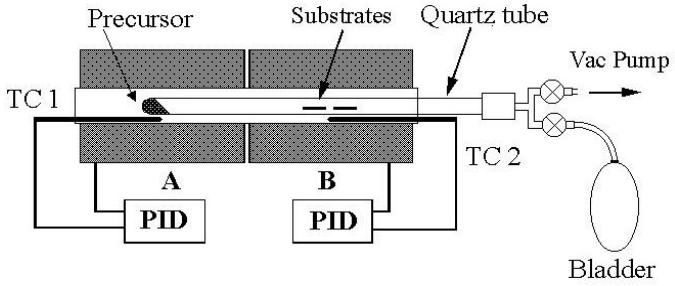

Fig.1. A double zone pyrolysis assisted chemical vapor deposition setup.

The amorphous carbon films prepared on unpolished substrates at 700^{o}C, 800^{o}C, 900^{o}C temperatures are taken out from the furnace after pyrolysis. Then the substrates are cleaned in acetone, and dried to avoid any dust particles on the emission surface that can yield erratic results. The cleaned amorphous carbon thin films are mounted on copper plate of 10mm in diameter. The substrates are of 5mm× 5mm size. We use silver paste to mount the substrate on the copper plate because that gives a good contact between substrate and the plate. The amorphous carbon thin film on the substrate that acts as a cathode mounted on copper plate sits on the platform of the emission unit. Gold plated tip of 1 mm diameter. has been used as anode. This whole unit is placed in vacuum. The positive terminal of the high voltage source (4kV) has been connected to the anode where voltage is supplied for electron emission from amorphous carbon

film cathode. Electron emission has been carried out on amorphous carbon films prepared at three different temperatures such as 700^{o}C, 800^{o}C and 900^{o}C. This has been done in the vacuum of 2×10^{-6} torr. The emission current has been derived indirectly by measuring the voltage across the 500kW resistor applying the voltage to the anode in step of 20V from 0V-1400V from a voltage source of 4kV.The cathode to anode distance is 150 μm, which remains constant while changing the voltage. The schematic diagram is shown in Fig.2.

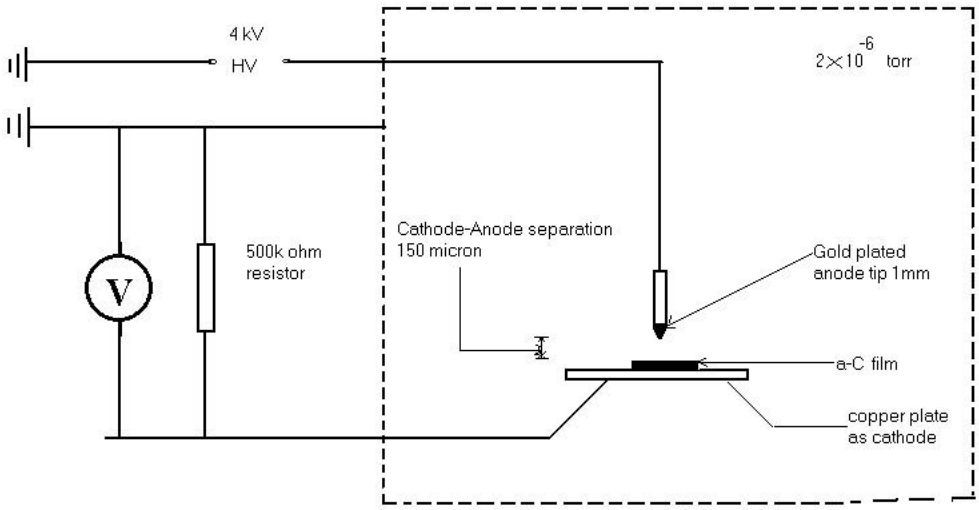

Fig.2. Schematic diagram of the experimental setup used to study the field emission performances of amorphous carbon films prepared at 700^{o}C,800^{o}C and 900^{o}C.

Results and discussion

The films prepared at high temperatures (900^{o}C) have more amount of sp^2 hybridized carbon network. The results are very clear from the Raman spectral studies, and also the electrical conductivity behavior. The films tend towards metallic when prepared at 900^{o}C. When samples are prepared at a lower temperatures the sp^2 content is less and shows low conductivity behavior, the film turns out to be insulating or semiconducting.

The higher the sp^2 content, the higher is conjugation leading to electron delocalization. Higher conjugation and sp^2 content needs a low applied electric field for onset of electron emission from the surface of the film.

This is very clear from the I-V plot where emission current is plotted versus applied field Fig-3. The emission current is considerably more for the sample prepared at higher temperatures (900^{o}C) than the sample prepared at lower

temperature (700^{o}C). The threshold field occurs when the steady-state emission current of 1nA is achieved. The threshold field for the sample prepared at temperatures 700^{o}C, 800^{o}C and 900^{o}C are 2.4 V/μm, 1.9V/μm and 1.6V/μm respectively. The threshold field depends on sp^2 content in amorphous carbon which leads to better conjugation which is found to vary with the preparation temperatures.

We have also studied the field emission of the samples of different thickneses (1.3μm and 1.8μm) prepared at 900^{o}C. We observe no change in the behaviour of current versus applied field characteristics Fig-4. Moreover we have observed no difference when the field is increased or decreased insert in Fig-4.

The classical explanation for electron field emission from a surface is Fowller – Nordheim(FN) tunneling behaviour. The Fowller-Nordheim emission current equation is as follows.

$I=AV^2\beta^2/\phi \exp(-B\phi^{3/2}/\beta V)$

Where, I =emission current(A), V=applied voltage, β =enhancement factor(for flat cathode β=1), ϕ=work function(eV), A and B are numerical constants.

The Fowller–Nordheim plots $\ln(I/V^2)$ vs 1/V of these a-carbon films show slopes that are linear, indicating that the emission mechanism is conclusively as electron tunneling phenomena.

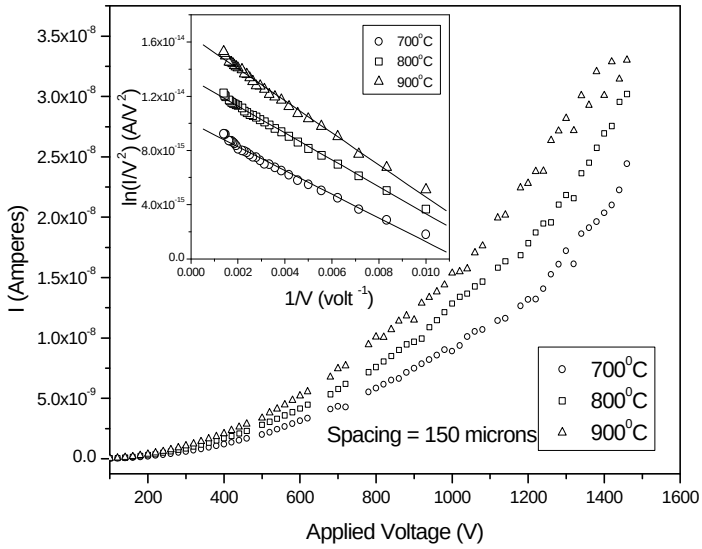

Fig .3.Emission I-V curves from a-C films prepared at 700^{o}C,800^{o}Cand 900^{o}C.The threshold fields for the samples are 2.4 V/mm, 1.9 V/mm and 1.6 V/mm. respectively.(inset)The corresponding Fowller - Nordheim plots. The linear relationship is observed in this ln(I/V^2) versus1/V plots

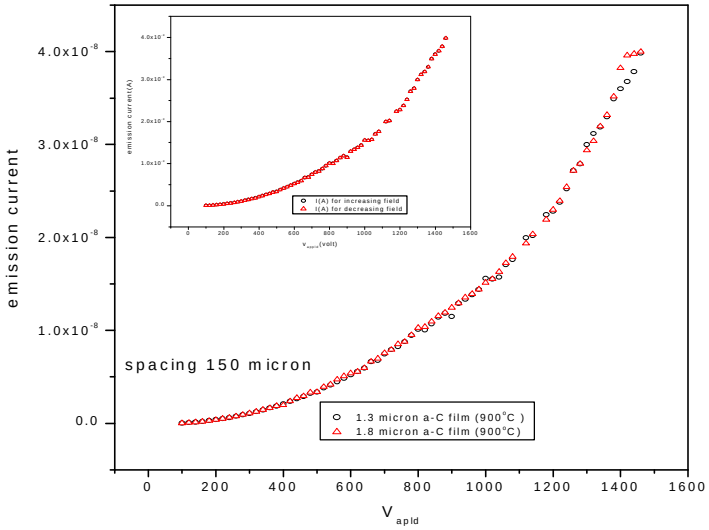

Fig. 4. Emission I – V curves of 1.3 mm and 1.8 mm thickness a-C films prepared at 900°C. (inset)The emission I-V curves of increasing and decreasing field.

Conclusions

The emission current depends on the amount of sp^2 hybridized carbon content in the amorphous carbon film. The sp^2 concentration and the conjugation depend on the preparation temperature. The FN plot of the experimental data gives a linear slope, which concludes that the emission mechanism is an electron tunneling phenomena. The field emission behavior is unaltered by varying the thickness of the film, which proves that the FE of the a-C is indeed a material property. It is well established that the electrical properties of carbon films prepared by the pyrolysis of organic anhydrides could be tuned to have metallic, semiconducting or insulating nature. Through this present work it is proved that the FE characteristics of the amorphous carbon also varies with preparation temperature, which essentially means that we could prepare these carbon films to suit our need of field emission. Based on the application needs, we could alter the preparation conditions and produce carbon films of desired FE threshold voltage.

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