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Study of the ability to field emission from diamond-like carbon layers and carbon nanotubes

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Abstract

The aim of this work was to study the relationship between parameters of the electron field emission and the film deposition method. In this study two methods were applied: classical radio frequency plasma-assisted chemical vapor deposition (RF PACVD) to produce diamond-like carbon (DLC) layers and chemical vapor deposition (CVD) to produce carbon nanotubes (CNT). DLC layers were grown on n-type silicon substrates and CNT were grown on n-type and p-type silicon substrates.

Atomic force microscopy (AFM) and Raman spectroscopy were used to investigate the physical and chemical parameters of DLC films after deposition process. The electrical parameters of capacitors with the DLC layer as an insulator were extracted from the capacitance–voltage (*C–V*) and current–voltage (*I–V*) characteristics. Measurements of the field emission were performed after characterization of the layer properties.

Keywords: Field emission; Cold electron emission; Carbon nanotubes; Dimond-like carbon; CNT; DLC

1. Introduction

The phenomenon of cold electron emission has been recently intensively investigated [1]. A number of applications based on this effect can be found in microelectronics, biology, chemistry and medicine. As we can find in the literature, diamond-like carbon (DLC) layers systems may have great ability to create negative electron affinity (NEA) region which is necessary for the existence of cold electron emission [1]. There are many plasma-assisted methods to produce DLC thin films: microwave, hot filament, radio frequency, etc. [2–4]. In all these processes we can produce DLC layers, but physical, chemical and electronic properties of materials are different. Layer morphology, especially the sp2/sp3 ratio, and nanocrystalline diamond inclusions have a large influence on DLC properties. In this study field emission current from DLC layer and carbon nanotube (CNT) were shown. In the experiments the RF plasma-assisted chemical vapor deposition (RF PACVD) method was used, because it is effective and relatively cheap in the case of DLC and CVD on modificated silicon substrates in the case of CNT, due to the fact that it is the most popular method to produce CNT [5].

2. Experimental procedure

All deposition processes were carried on silicon substrates. In the case of DLC layer (sample Z3a) the n-type $\langle 1\,0\,0 \rangle$ silicon wafers characterized by 2–10 Ω cm resistivity were used as substrates, while in the CNT case they were n-type $\langle 1\,1\,1 \rangle$ silicon wafers characterized by 0.002 Ω cm resistivity (sample 76NiF07CNT [A]) and p-type $\langle 1\,1\,1 \rangle$ silicon wafers characterized by 0.002–0.020 Ω cm resistivity (sample 77NiF07CNT [D]). As we can find in the

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Table 1
The parameters of DLC deposition process

	Z3a
Negative self-bias potential (V)	~300
Pressure (Pa)	41.1
CH_4 flow (ml/min)	20
Ar flow (ml/min)	5

Table 2
The parameters of CNT deposition process

	76NiF07CNT [A]	77NiF07CNT [D]
Predeposition processes		
Time (min)	60	20
Metal	Nickel	Nickel
I_{C60} [A]	1.9	1.9
I_M [A]	1.1	1.1
CVD process		
Ar flow (l/h)	40	40
C_6H_4 $(CH_3)_2$ flow (l/h)	6	6
Temperature (°C) (1st zone, 2nd zone)	180, 650	180, 650

literature, n-type silicon with DLC layers systems may have great ability to create NEA regions, which are necessary for existence of cold electron emission.

Main parameters of the deposition process are presented below in Table 1. In Table 2 main parameters of CNT processes are presented. The method of deposition of the CNT was described in [4].

After the deposition process, before the field emission current measurements, additional tests were carried out, which characterized the silicon-DLC system and the DLC layer in metal–insulator–semiconductor (MIS) structure. The electronic properties of MIS capacitor were calculated from the results of high-frequency capacitance–voltage (C–V) and current–voltage (I–V) measurements. The carbon layers played the role of insulators in the investigated MIS structures. The surfaces of carbon layers were investigated with the atomic force microscope (AFM). The field emission was measured under the following conditions: voltage from 1.4 to 4 kV, distance between electrodes in range 0–1 mm and pressure in chamber equal to 1 mPa.

3. Results and discussion

Based on parameters of depositions of DLC it can be said that layers are typical. That conclusion was confirmed by the results of Raman spectroscopy investigation, which are shown in Figs. 1 and 2.

Plots of field emission current as a function of the electric field are shown in Figs. 3 and 4. For CNT samples (Fig. 3)

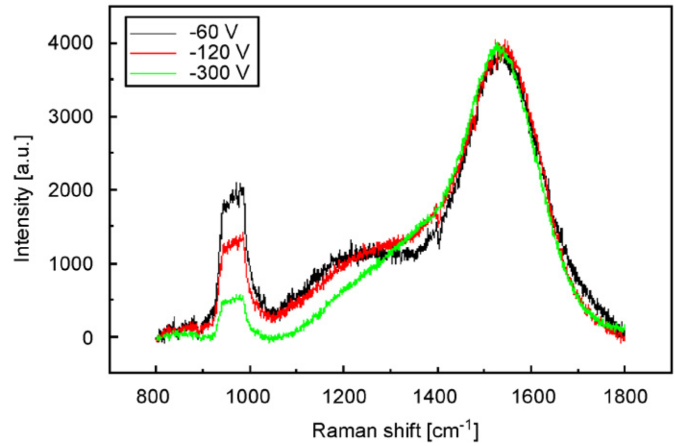

Fig. 1. Raman spectrograms of the DLC layers.

increase in the current has a logarithmic character, but in Fig. 4 logarithmic character increases are not so obvious. Fig. 4 shows two almost constant current levels, the first in the range of electric field from 23 to 27 V/μm and the second from 29 to 34 V/μm. The first level is not as obvious as the second one. The difference in value for the above two ranges is almost a decade. Above electric field value of 34 V/μm, the films were completely destroyed. These two fragments of the plot in Fig. 4, illustrate how energy was provided to the layer, for conductive channel creations. The mechanism of electron emission from CNT is different than the mechanism of emission from DLC. In Fig. 3 we can observe field emission current from two samples of CNT. As can be expected the turn-on field is lower for CNT samples than for DLC sample. For sample on n-type substrate (76NiF07CNT [A]) the turn-on field has the value of 7.5 V/μm, and for sample on p-type substrate (77NiF07CNT [D]) the turn-on field has the value about 9.5 V/μm. For the DLC sample (Z3a) the turn-on field has the value over 20 V/μm.

After comparison of two plots (Figs. 3 and 4) of the field emission current from CNT samples, it was observed that the value of current for the same value of electric field is higher for the sample on n-type silicon substrate, but CNT on p-type silicon substrate has better adhesion to the substrate than CNT which has been grown on n-type substrate. The tunneling character of current was confirmed by the Fowler–Nordheim plots (Figs. 5 and 6).

Comparing of Figs. 5 and 6, it is observed that the Fowler–Nordheim plots for CNT are more regular than the plot for the DLC sample. In Fig. 6 semi-constants fragments can be observed. There is a combination of two almost constant current levels from Fig. 4.

4. Conclusions

The current of field emission for CNT samples has a higher value under the same conditions as DLC ones