Workstation for Automated Measurement of Electron Emission Characteristic of Samples Covered by Carbon Nanotubes

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Abstract. *The paper deals with an automated current-voltage measurement of the cold electron emission characteristic. A measured sample was NI wire covered by a layer consisted of carbon nanotubes (CNT). The CNT were fabricated at Department of Microelectronics. The technology of preparation is briefly described. A compact high voltage converter (source of high voltage) controlled by a commercial digital low voltage power supply was used. Both the digital power supply and the multimeter were controlled by a PC through a USB/GPIB interface.*

Keywords: Automated Measurement, Field Emission, Carbon Nanotubes, Hot Filament CVD

1. Introduction

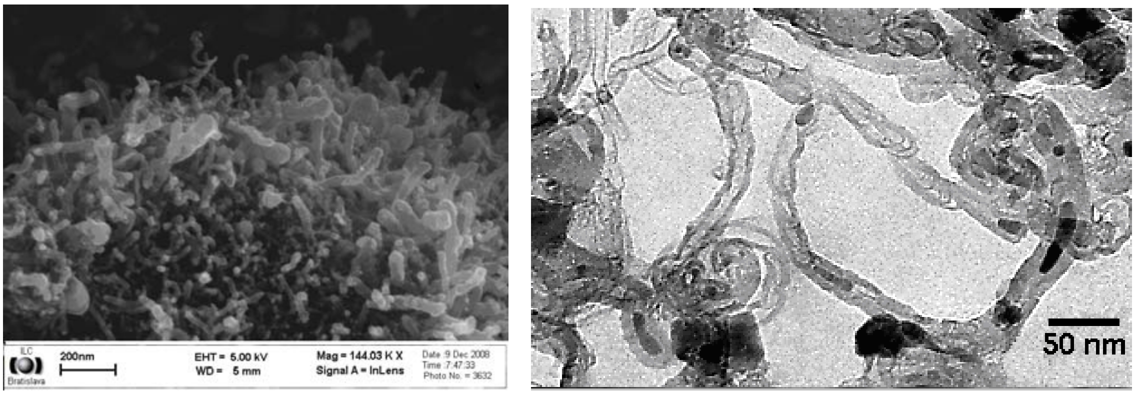
Carbon nanotubes (CNT) are one of known allotrope forms of carbon. The CNT were first described by Iijima [1]. Since that time a number of other kinds of nanotubes were studied and different properties of the CNT were found. Metalic CNT, semiconducting CNT, single walled or multiwalled CNT were studied. The CNT properties are chirality dependent [2]. Due to high length to diameter ratio an electric potential applied between cathode and anode creates great electric field in a vicinity of an individual CNT and cold electron emission occurs (cca 10^8 V/m). This effect can be exploated for cold electron emitters. Semiconducting CNT can be used for FET transistor production. Metalic CNT can be added to the polymers or sheets of papers to avoid their electrostatic adhesion properties. Also CNT are known as a hydrogen reservoar for vehicles, which (maybe in the future) replaces oil/petrol/alcohol/gas by the hydrogen. A heat conductivity of nanotubes is extremely anisotropic. It can be used for special coolers. The mentioned electron emission properties has a wide field of application. Because of the analogy of electron tubes known in the thirties, a micro-electron-tubes with the CNT cathodes, named as „vacutrons“, can be fabricated. They can be used up to terahertz frequencies. The displays known as a „CNT FED“ (Field Effect Displays) are very promissing. The CNT can be used also for an space propulsion vehicles [3].

2. Subject and Methods

Apparatus for CNT preparation
Many kinds of preparations the CNT are known (arc, laser ablation, chemical vapour deposition -CVD-, electrolyse in organic liquids, etc.). We used a modified CVD technology. The apparatus (CVD reactor) was made after S. Bederka‘s design.

Nanotubes identification
For nanotube identification a few analyzing techniques are used. Most promissing and often used is an Scanning Electron Microscopy (SEM). Also a Transmision Electron Microscopy

(TEM) is convenient. The TEM is rather expensive, but a resolving power of the TEM is excellent. Atomic Force Microscopy (AFM) was made, but result is not shown here.



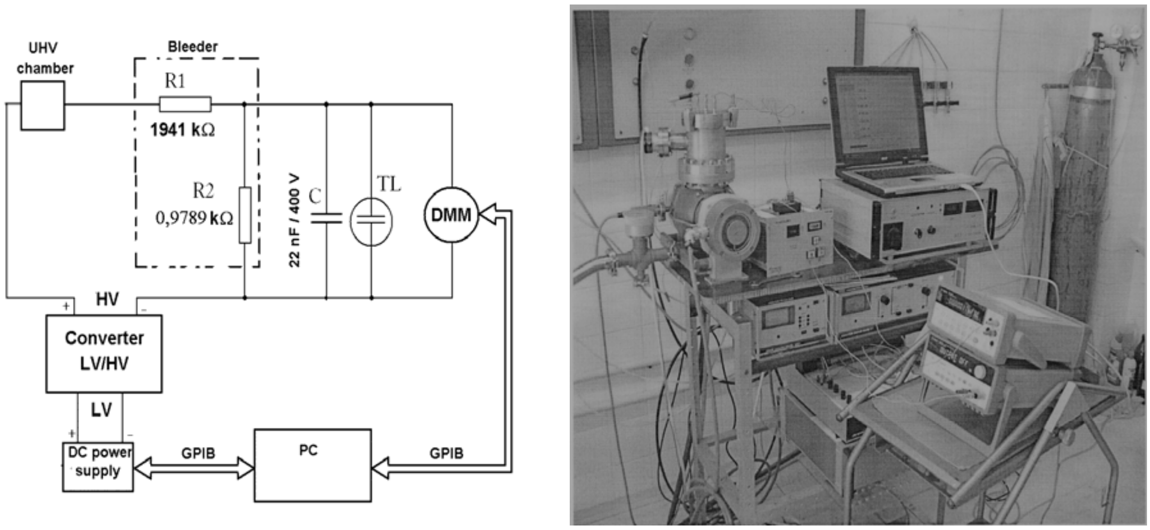
a) b)

Fig. 1a,b. SEM and TEM images of CNT.

Due to a special preparation of sample one can see (Fig. 1b) a structure of an individual nanotube [4]. For CNT identification the Raman spectroscopy is used very often. The Raman spectroscopy was used also in our case, but the results are not reported here.

Experimental measurement

The block diagram of the measurement setup is shown in the Fig. 2a. The view of the workstation is in Fig 2b. The workstation consists of ultra-vacuum chamber evacuated by a turbomolecular pump, low voltage/high voltage converter (LV/HV), digital multimeter, digital power supply, USB/GPIB interface and PC with MS EXCEL software.



a) b)

Fig. 2a,b. Block diagram and view of workstation for cold electron emission measurement

List of used devices:

- DMM - digital multimeter Agilent technologies 34401A
- DC power supply - DC Power Supply Agilent technologies E3641A
- GPIB - Agilent 82357B USB/GPIB Interface High-Speed USB 2.0
- Converter LV/HV- converter Emco (Hivolt.de) F40 Series
- TL - glow-discharge tube

The properties of AGILENT devices are available in [6]. The converter LV/HV has some properties published, but not its linearity. In spite of possibility of this converter to work up to input voltage 15 V, for our purposes the maximum voltage was only 4 V. To evaluate the linearity of the converter we measured its transfer function. Then the substitution line for input voltage 1.6 - 4.0 V was calculated. By this procedure we found out that the linearity error in this range was max. ±0.05 %.

Measurement Procedure

The measuring of electron emission is a macroscopic process. On the surface of Ni wire there are many emitting nanotubes. Some of them are partially damaged in the process of measuring. The long CNT are damaged primary because they are settled and burned in the presence of high electric field. Due to this fact, the measurement should be made as quickly as possible. It is not realizable by the manual measurement. The damage is great at the beginning of the measurement. After some time the current has character of saturation. After our experience the saturation current after some hours reaches about 70 percent of the beginning values. The automation of the measurement gives us a possibility to quantify better the saturation process due to the shorter sampling time compare with the manual measurement. Due to the accuracy of used measuring devices the estimated precision of the measurement is better then 0.1 %. Because of the CNT damaging process the change of the emission current is much worse than mentioned precision.

3. Results

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	A	B	C	D	E	F
4	Voltage	U1	Teoret	Output\	Current	Field [V/um]
5	0	-0,0003	0	9E-07	9E-10	0
6	0,1875	-0,0002	50	3E-06	3,02E-09	0,2038043
7	0,375	-0,0002	100	3E-06	3,18E-09	0,4076087
8	0,5625	0,02584	150	3E-06	3,43E-09	0,611413
9	0,75	0,05178	200	4E-06	3,67E-09	0,8152174
10	0,9375	0,0644	250	4E-06	3,64E-09	1,0190217
11	1,125	0,07426	300	4E-06	3,7E-09	1,2228261
12	1,3125	0,08253	350	3E-06	3,29E-09	1,4266304
13	1,5	0,08978	400	4E-06	4,48E-09	1,6304348
14	1,6875	0,09617	450	4E-06	4,03E-09	1,8342391
15	1,875	0,10193	500	2E-05	1,68E-08	2,0380435
16	2,0625	0,10708	550	0,0001	1,12E-07	2,2418478
17	2,25	0,11177	600	0,0005	5,38E-07	2,4456522
18	2,4375	0,11591	650	0,0017	1,66E-06	2,6494565
19	2,625	0,1199	700	0,0043	4,35E-06	2,8532609
20	2,8125	0,12407	750	0,0082	8,23E-06	3,0570652
21	3	0,12711	800	0,0123	1,23E-05	3,2608696
22	3,1875	0,12999	850	0,0192	1,92E-05	3,4646739
23	3,375	0,13357	900	0,0272	2,72E-05	3,6684783
24	3,5625	0,13605	950	0,035	3,5E-05	3,8722826
25	3,75	0,13942	1000	0,0448	4,48E-05	4,076087
26	3,9375	0,14307	1050	0,0568	5,68E-05	4,2798913
27	4,125	0,14684	1100	0,0684	6,84E-05	4,4836957
28	4,3125	0,15129	8,66	0,0803	8,03E-05	4,6875
29	4,5	0,15554	8,66	0,0922	9,22E-05	4,8913043

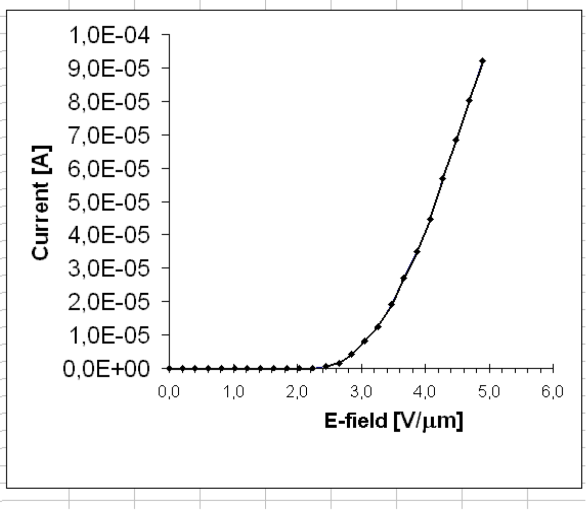

Fig. 3. Measured and calculated values and calculated graph.

The I-V characteristic of Ni wire (cathode) covered by CNT was measured. The sample was prepared after [5]. As an example of automated measured data there is shown a sheet „xls“ of EXCEL in Fig. 3. There are the measured values and drawn graph of emitted current versus electric field. In the chamber anode-cathode electrodes have a cylindrical symmetry. The mean value of the electric field on the cathode was calculated by (1)

$$E = \frac{V}{r_1 \ln \frac{r_2}{r_1}} \qquad (1)$$

where

r_1, r_2 radius of cathode and anode

V anode potential.

4. Conclusions

An automated workstation for measuring the I-V characteristics of described CNT was realized. The emission current was involved by an field emission in the strong electric field. The measured dependance of current versus voltage was recalculated to the dependance of current versus electric field. The graph of this dependance was immediately drawn. From the measured values other interesting data (treshold voltage, work function, etc.) can be extracted. Next advantage of automated measurement setup is that no special cards for PC are needed. So the notebook can be used (as it was in our case). A big asset of the automated measurement is shorter measuring time. More, the measuring process avoids subjective mistakes. Compared with the measurements made manually some quantification of damaging process of CNT can be better estimated. The whole measuring process is more effective than it was before. Also there is no need of permanent presence of operator during long time measurements (some days). An optimal sampling time remains an open question, but this will be a task for further work.

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