

PHYSICAL PROCESSES ON THE SURFACE OF FIELD EMISSION CATHODES BASED ON CARBON NANOSTRUCTURAL MATERIALS

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Introduction

At present time field emission cathodes based on different carbon nanostructural materials became popular. Lifetime is a very important characteristic of the field emission cathodes. Generally there are two main degradation stages for planar cathodes based on carbon materials such as nanotubes, nanohorns, nanographites and so on [1,2]. First of them is characterized by a change of cathode work function. It results in significant variations of emission current and, therefore, in rapid cathode degradation. This stage ordinary takes place right after high voltage is applied between cathode and anode. Its duration doesn't exceed a several minutes. After that another stage is began. It is described by slow, practically linear, function during operation time. This stage is connected with decreasing emission area or number of nanopaticles. The typical long-term experiment aimed at emission stability investigation of cathode based on carbon nanostructural materials is represented on figure 1.

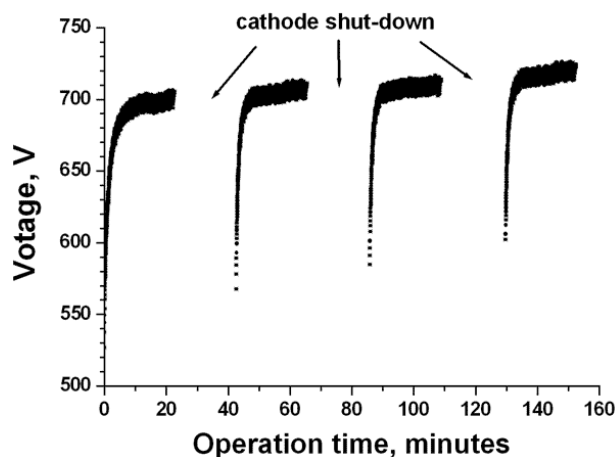


Fig. 1. Typical long-term experiment for field emission cathode based on carbon nanomaterials. Emission current is remained a constant at 100 μ A.

In this work a physical processes, which lead to variations in cathode work function, is considered. Also the numerical model, which is described field emission cathode degradation due to these processes, is proposed. Using proposed model it is possible to predict cathode lifetime and its behavior for a long time.

Model description

Developed model is based on following assumptions. During storage time molecules of residual gases are adsorbed on a surface of the field emission cathode. Using results of the latest theoretical work [3, 4], in which the effect of different gases molecules adsorption on electronic properties of single carbon nanotube is considered, it is possible to assume that some molecules (with polar moment) adsorption is able to change a cathode work function. Then voltage is applied between cathode and anode, adsorption layer is destroyed due to ion bombardment. At the same time the value of cathode work function is restored to its magnitude for clean carbon surface.

The numerical description of model is based on following key assumption:

1. Adsorbed atoms on a surface of the field emission cathode can exist in two different states. In first state gas molecule is attracted to an adsorbent by only dispersion forces. The given state corresponds to a case of physical adsorption, which is characterized by relatively small bond energy of an adsorbent-adsorbed atom system. Also another process – chemical adsorption – is possible. In this case there is a partial interchanging by conduction electrons between an adsorbent and adsorbed atom, i.e. the strong chemical bond will arise.
2. Besides there is some activation barrier, having overcome which one the gas particle can pass from the first state to second.
3. If voltage between anode and cathode is applied, ionized neutral molecules of residual gases are accelerated in an electrical field and bombard a cathode. Thus there is a clearing of a cathode surface from different films of oxides and impurities due to process of cathode sputtering depicted elsewhere [5].
4. We consider that at ion impact in a cathode surface causes a rapid heating of some small cathode area, which results in local explosion. Thus the given surface area is completely (or almost completely) cleaned from adsorbed atoms. Then due to migration process the equilibrium distribution of gas particles on cathode surface is formed again.

The characteristic time of such process is much lower, than time of thermal desorption as energy threshold at surface migration is below by several times than one at adsorption (bond energy). Thus, it is possible to consider, that the ion bombardment uniformly cleans a cathode surface with large efficiency.

Simulation results

Using a proposed model the numerical computation of a covering degree variation on the field emission cathode surface by residual gas molecules was carried out. Also a dynamic of work function during a cathode storage and operation time was calculated. An example of such calculations is shown on figure 2.

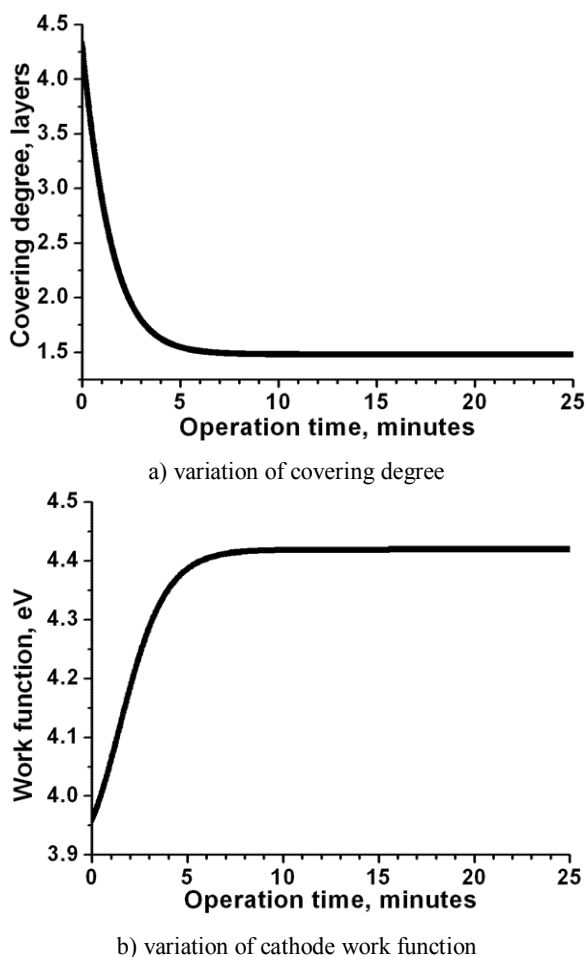


Fig.2. Simulation results for a field emission cathode based on carbon nanotubes during its operation time.

For simulation the following values of arguments were selected. Bond energy in physical adsorption state is assumed to be equal to 0.5 eV, pursuant to value for oxygen. Activation energy for

the oxygen is 0.84 eV, and bond energy in chemical adsorption state – 6 eV [6].

Conclusions and discussion

The calculated results were compared to experiment data. In all cases the proposed model describes a behavior of the real device rather well. Therefore one can use it for a simulation of transient processes, which take place at actuation/shut-down of the field emission cathode. For instance, using proposed model it is possible to develop an optimal feedback system for the purpose of providing a long-time emission current stability. Moreover, taking into account information about an adsorption of different gases on carbon nanotube [3, 4] it is possible to select such working conditions of the field emission cathode (gases mixture) that an operation voltage will be decreased.

In addition the above-mentioned prospects are probably applicable to field emission cathodes based on carbon materials in general, and not just only for nanotubes. The given assumption is grounded on investigation results of long-time stability of field emission cathodes based on natural, thermo-enlarged graphite and carbon fibers. To make the final conclusions about application field of the proposed model it is necessary to carrying out additional investigations.

In more detail developed model (its quantitative description), testing technique and the results of experiments will be presented in the report.

References

1. V.S. Bormashov, R.G. Tchesov, A.S. Baturin, K.N. Nikolski, E.P. Shehsin. IFES 04 Abstracts book, Graz, Austria, 2004, p. 109.
2. V.S. Bormashov, R.G. Tchesov, A.S. Baturin, K.N. Nikolski, E.P. Shehsin. ICAP 2004, Abstracts book, St. Peterburg, 2004, p. 122.
3. A. Maiti, J. Andzelm, N. Tanpipat, and P. von Allmen. Phys. Rev. Lett. 87, 2001, p. 15.
4. R. Collazo, R. Schlessner, Z. Sitar. Diamond and Related Materials 11, 2002, p. 769-773.
5. E. B. Henschke. Phys. Rev. 121, 1961, p. 1286.
6. Zhu X.Y., Lee S.M., Lee Y.H. Phys. Rev. Lett. 85, 2000, p. 2757.