DOI: 10.17277/amt.2018.01.pp.052-057

A Review of Power Source for Nanostructured Carbon Materials in Cathodoluminescence Light Sources

Nyein Chan Kyaw*, E.P. Sheshin, L.N. Win, Z.Y. Lwin, H.W. Aung

** Moscow Institute of Physics and Technology (State University), 9, Institutsky per., Dolgoprudny, Moscow region, 141701, Russia*

* Corresponding author: Tel.: +7 (495) 408 45 54. *E-mail*: maungnyeinchanlay@gmail.com

Abstract

Currently, power supply sources are widely used in electronics and other modern technologies. Field emission devices of carbon materials require special power sources, basic characteristics of which are discussed in this paper. Power supply for devices with field emission cathodes of carbon materials must be small, have high efficiency and be able to integrate with the device. Cathodoluminescent light sources have several advantages over other sources, in particular, the switch on/off of the higher brightness and speed. At present, auto emission cathodes based on carbon materials, including nanostructured cathodes, are beginning to be used in such sources. The results of the studies of the emission properties of various carbon materials show the promise of their use as autoemitters [1]. The use of field emission allows expanding the range of operating temperatures, reducing inertia, increasing the service life and improving the environmental friendliness of cathode-luminescent sources.

Keywords

Cathode; carbon material; field electron emission; cathodoluminescent light sources.

Introduction

Carbon materials that are used as auto emitters are divided into several groups (see Table 1). Such a division is conditional, and it is based on the method of obtaining a carbon material. Carbon can be in various forms, for example, amorphous carbon [2], fullerenes [3], nanotubes [4]. Basically, the obtained structure and its properties are determined by the method and technological parameters of production.

Emissive properties of structural carbon materials

The field emission characteristics of a cathode made of graphite are determined mainly by the parameters of microprotrusions on its emitting surface. Therefore, when studying the emission properties of autocathodes of different types, the autoemission properties and the surface structure are compared. The surface roughness of high-strength graphite was investigated in [5, 6]. Roughness is understood as a quantity that is inverse to the average radius of curvature of the microprotrusion forming the surface

Table 1
Types of carbon materials

Material type	Basic views
Construction materials	High-strength graphite
	Pyro carbon
	Glass-carbon
Carbon fibers	Polyacrylonitrile-based
	Bake-based
	Pyro carbon
Carbon Nanomaterial	Alamase-like films
	Nanotubes
	Fullerenes

of the autocathode. In [5, 6], we gave the qualitative results showing a significant effect of the roughness of the autocathode surface on the emission current magnitude. The roughness of high-strength graphites, in particular of PGM-6, can be changed due to various types of temperature and mechanical treatment of the surface of the cathode. In addition, an effective method of improving the emission properties is the training (shaping) of the autocathode [7]. It is noted that after molding, the microstructure of the working surface, and consequently the stability of the emission current relaxes to some optimal value, which is determined by the microstructure of the initial graphite, the working area, the required current collection, and the anode-cathode distance.

One of the promising methods of improving the autoemission properties of carbon materials is the radiation treatment of their surface by low-energy ions in a corona discharge plasma [8]. The experiments showed that the radiation treatment makes it possible to obtain the developed surfaces of carbon materials with a large number of emission centers.

Autoelectronic emission from pyrographite is extremely anisotropic. The experiments on the study of the emission properties of pyrographite showed that the maximum value of autoelectron emission from it can be obtained from the ends of pyrolygraphic plates, while no emission is observed from their plane.

It was shown in [9, 10] that the limiting current of autocathodes from pyrographite increases with the temperature of the thermal treatment of the carbon material, under the action of which a change in its structure takes place. The level of instability of the field current for all samples was constant at low currents (up to 1–10 μA and decreased with increasing current at large (more than 1 mA) values. The lowest value of instability (about 9 %) at currents less than 1 μA and autocathodes of pyrographite with a thickness of 30 μA with a treatment temperature of 2000 °C. At 2500 °C the greatest instability for cathodes with thermal treatment was about 27 %. At 3–6 mA emission currents, the instability for all samples was 1–2 %.

Features of work of autocathodes emission

One of the main properties of autocathodes (**AECs**) from carbon materials that determine the possibility of their practical use is the stability of emission under conditions of a vacuum. The term “stability” means the absence of current-field fluctuations and irreversible emission changes that could significantly affect the shortening of the service life of the field electron cathode.

One of the causes of deterioration in the emission or even destruction of the emitter is the vacuum arc, which arises from the presence of residual gases or from the sputtering of the cathode material with a significant emission current. This phenomenon is observed when the electric field becomes higher than a certain critical value. In this case, an arc or spark discharge can arise in the system, resulting in irreversible destruction of the cathode material [1].

Another cause of instability in the operation of the AECs is the bombardment of the emitter by positive ions of residual gases. Electrons emitted by the cathode as they move toward the anode, ionize the atoms of the residual gases, as well as the atoms and molecules of various substances emerging from the glass and electrodes of the device. Positive ions formed in this process, get accelerated in the electric field, move to the emitter and bombard it, possessing a significant average energy determined by the voltage between the anode and the cathode [1].

Another significant factor affecting the degradation of the AEC is the warming up of the emitter by Joule heat. Taking into account the influence of heating by current is especially important when considering nanoscale emitters. Since S is the area of contact of the emitter with the substrate-only a few tens of square nanometers, the resistance of such a system ~ $1/S$ is very important. In vacuum conditions, the main heat removal is carried out through the substrate and the amount of heat removed is small. The totality of these factors leads to a substantial heating of individual emission centers [1]. Such a strong local heating (up to temperatures of the order of 2000 K) was observed in auto electron emission from nanotubes. At such temperatures, it is no longer the field-electronic one, but the thermo-auto-electronic emission. In these conditions, CNTs can rapidly decay (evaporate), which leads to the disappearance of this emission center.

It should be noted that the mechanical effect of the field on the properties of field-emission cathodes is based on nanotubes. It is known that carbon nanotubes in an electric field tend to orient themselves along the field under the action of ponder motive forces. Because of reorientation, the field gain increases. However, in addition to this useful effect, a negative effect is also observed – a sharp weakening of the mechanical and electrical contact of the nanotube with the substrate.

However, the greatest influence on the stability of the auto emission current is caused by a modification of the surface properties of the cathode upon adsorption of residual gas atoms on it, and their desorption by ion bombardment. It can be noted that only the adsorption of oxygen and water vapor has a significant effect on the electronic properties of the tube. In this case, oxygen molecules increase the ionization potential (work function), and water molecules, on the contrary, decrease.

Thus, it can be concluded that despite the impressive amount of experimental data the issue of the stability of the emission current of AEC from various nanocarbon materials remains open. It is not clear what conditions, and what factors determine the stability of operation of a particular cathode. Because of the large number of factors and their complex influence on the process of field emission, there is no final model describing the degradation and fluctuations of the emission current. Investigating the stability of emitters and determining the factors influencing it are necessary for determining the optimal operating modes of such cathodes.

Light sources with autocathode from carbon materials

The main directions in the development of light sources with autocathodes based on carbon materials are the creation of flat light sources with film cathodes, finger cathodoluminescent lamps and light sources with axial design.

Flat light sources. The main design difference between plane light sources is the large area of the anode (cathode) and the small distance between the cathode and the anode in comparison with the linear dimensions of the cathode substrate.

With a suitable technology for the production of flat electro-vacuum devices, it is possible to develop a light source with an area of more than 500 cm^2. Such devices can have a diode or triode design. A triode design is preferable for creating super-bright light sources. In flat light sources of low brightness (1000–5000 cd/m^2), a diode design is used, which greatly simplifies the production of a vacuum device. Such devices can be used in the illumination of liquid crystal screens [16].

Autocathodes for flat devices can be manufactured by various methods, for example, by screen printing or electrophoretic deposition. It is advisable to use carbon powders obtained with the help of various technologies as a deposited material. In addition, mechanical methods for machining a massive carbon billet can be used to create a large field-area cathode-shaped cathode.

The prototype of a flat field emission diode light source (Fig. 1), whose cathode was made of nanostructured carbon based on oriented nanotubes and nanosized carbon crystallites was developed and described in [17]. The presented sample 3 mm thick had a uniform brightness of 500 cd/m^2 at a surface of 25×25 mm.

At present, the efficiency of light sources with cathodes on nanotubes is investigated [18, 19]. The prototype of such a luminescent diode is presented in [19] (Fig. 2). Nickel wire of 1 mm thick coated with nanostructured carbon was used as material for the cathode. The cathode was placed coaxially with a 20 mm cylindrical glass tube, half of the inner surface of which was coated with an aluminum film (anode), and a phosphor layer was deposited on top of the aluminum. The brightness of the diode reached 100,000 cd/m^2 at an anode voltage of 10 kV and a current of 300 μA. The luminous flux of such a light source was 150–200 lm with a light efficiency of 25–30 lm/W.

The cylindrical anode (in the form of a glass bulb with a luminescent coating applied), a modulator (control electrode in the form of a cylindrical grid), and an oblong cathode, whose construction and material can be any, were coaxially located in the axial light source of the triode structure.

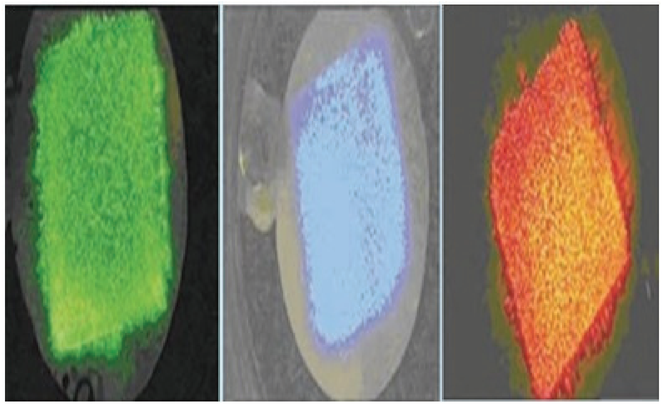

Fig. 1. Flat field emission light emitting diode (with various phosphors)

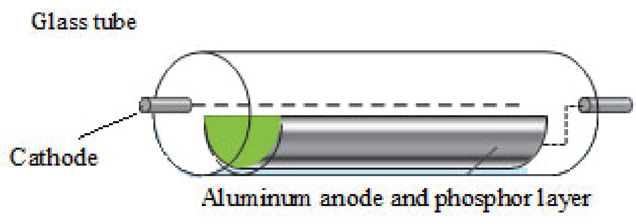

Fig. 2. Cylindrical diode lamp with cathode from nanostructured carbon

Finger cathodoluminescent lamps. Finger cathodoluminescent lamp is the brightest light source by its design. In this design, a voltage between the cathode and anode of up to 10–15 kV and a current of up to 1 mA can be realized. The brightness of such lamps can reach 100,000 cd/m^2 or more. The field of their application is elements of medium and small resolution video screens.

One of the options for a finger lamp is a cathodoluminescent triode with an auto-cathode based on carbon fiber bundles. The cathode of such a device consists of several beams of PAN carbon fibers with ~ 100 fibers in each and gives a stable emission current of up to 1 mA with good uniformity of illumination of the luminescent anode.

Another option is a bright cathodoluminescent lamp of a triode design with an auto-cathode based on nanotubes. The green brightness for this light source is 60,000 cd/m^2 (at anode current of 200 μA). In a later version of the light source.

The brightness of the radiation reaches already 1,000,000 cd/m^2, and the luminous flux is 1000 lm. This brightness was obtained with a constant current sampling at 400 μA and an accelerating voltage of 30 kV. With such accelerating voltages and output power, the light source is equipped with X-ray shielding (lead glass) and a heat dissipation system.

Sources of light developed in the authors' laboratory (Department of Vacuum Electronics, MIPT)

More than 100 cathodeluminescent lamps of a triode design with a cathode made of PAN-fibers were fabricated to determine the emission properties and refine the cathode manufacturing technology (Fig. 3, 4). The light and emission characteristics of the experimental batch of these light sources were investigated for the spread of cathode parameters, as well as their work in the prototype of the video screen module.

Fig. 3.Cathodoluminescent lamp

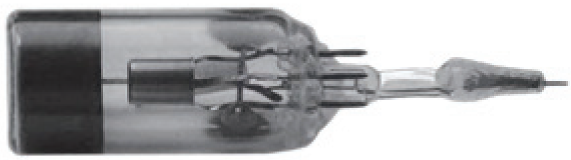

Fig. 4. Cathodoluminescent lamp of a triode structure with an auto ionic cathode

The investigation of the photoelectric characteristics of lamps was carried out on a prepared specialized measuring stand, with the help of which data were obtained on the emission spectrum of lamps, their brightness and light efficiency (Fig. 5, 6).

For each lamp from the test batch, four volt-ampere characteristics were taken (the dependence of the field emission current of the cathode IK on the modulator voltage at a fixed anode voltage U_A = 7, 8.9, 10 kV was taken) (Fig. 7).

Based on the experimental data on the volt-ampere characteristics of each cathodoluminescent lamp (Fig. 8), several points should be noted. First, the current-voltage characteristics of all light-emitting pencil lamps from the test batch lie in the control voltage range U_m [$I_{k\,\max}$ = 100 μA] < 1500 V (Fig. 8).

Secondly, the current-voltage characteristics of the cathodoluminescent lamps are not shifted to the region of negative control voltages, but on the contrary, at some positive potential on the modulator the field emission current is practically absent: U_m [$I_{k\,\max}$ < 0.5 μA] > 500 V.

Thirdly, it is obvious that there is a noticeable variation in the values of the control voltages of the modulator ΔU_m [$I_{k\,\max}$ = 100 μA] ~ 300–400 V (Fig. 8). Apparently, such a spread of characteristics is associated with a set of technical reasons: the inaccuracy of the cathode installation in the holder, the inaccuracy of the modulator-anode distance setting during the vacuum coating of the lamp, the small spread of the lengths of the carbon fiber bundles, and the different number of fibers in the beam for each lamp.

Using these lamps, the elements of video screens were created.

Perspective fields of application of light sources with an autocathode

The spectrum of application of cathode-luminescent light sources with AEC is wide. This, in particular:

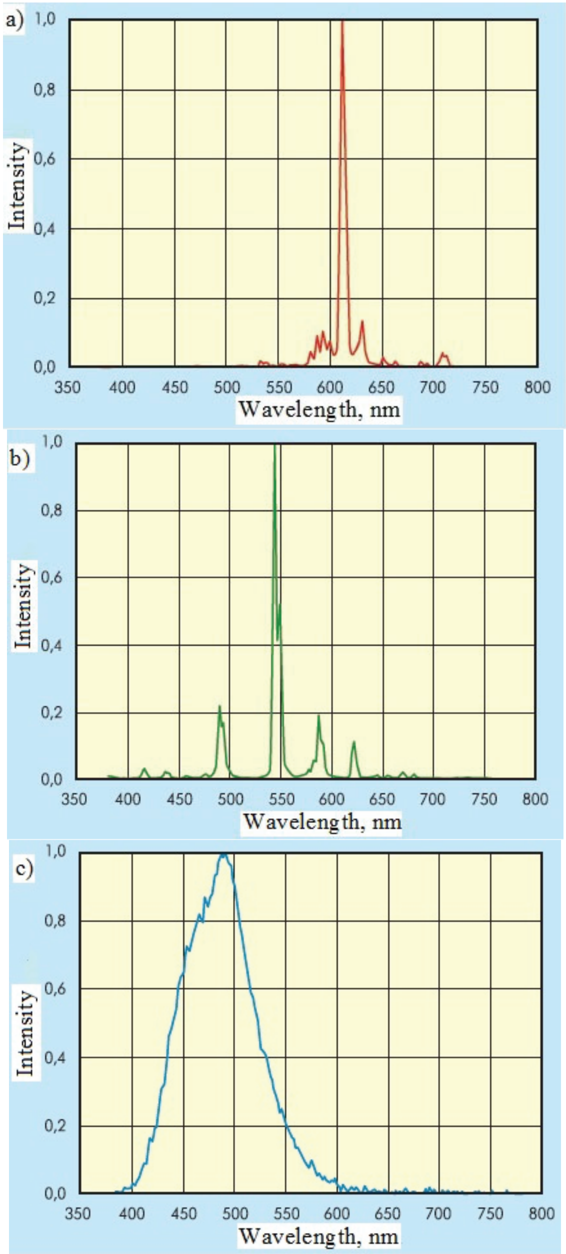

Fig. 5.The emission spectrum of a lamp of red color (*a*), green color (*b*) and blue color (*c*)

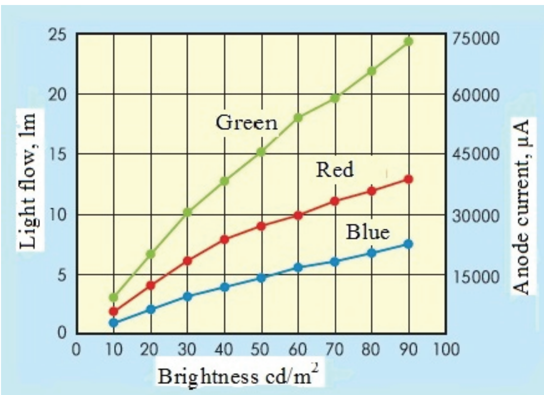

Fig. 6. Dependence of radiation brightness and the light flux of the finger on the value of field emission current

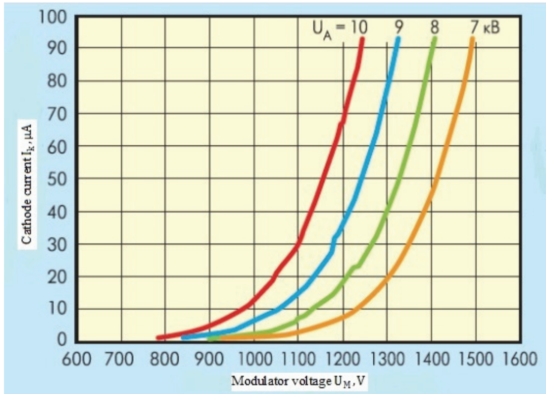

Fig. 7. Typical current-voltage characteristic of the lamp from the test batch

(Dependence of the field emission current I_k of the cathode on the voltage at the control electrode U_m at fixed voltages at the anode U_A = 7, 8, 9, 10 kV)

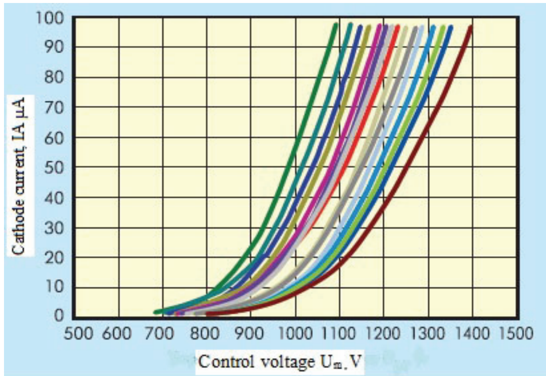

Fig. 8. Volt-ampere characteristics of various lamps from the test batch

(Dependence of the field emission current I_k of the cathode on the voltage at the control electrode U_m at anode voltage U_A = 10 kV)

Light lamps (Fig. 9*a*).

• Elements of LCD backlighting (Fig. 9*b*).

• Field Emission Display FED.

• Pixels of large video screens of collective use (Fig. 9*c*).

• Traffic lights and semaphores.

• Sources of backup lighting.

• Salvage signals on the water and in the mountains.

• Any high-brightness light source with the ability to select the emission spectrum.

A cathodoluminescent light source makes it possible to obtain visible radiation, the spectral composition of which is favorable for visual perception and does not cause such eye fatigue as most known light sources. There are no harmful infrared and ultraviolet radiation in cathodoluminescent radiators.

Light from cathodoluminescent sources can be obtained diffusely, or directed into the required solid angle in special applications, such as video screens of collective use.

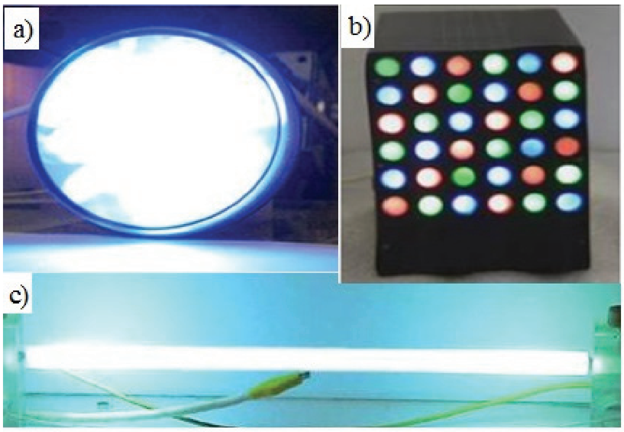

Fig. 9. Perspective light sources based on auto-cathode of carbon materials:
a – a lighting lamp; *b* – a lamp to illuminate the LCD display; *c* – pixels of large video screens

Cathodoluminescent lamps with autocathode in its composition do not have toxic materials and gases harmful to human health. For such light sources, production and disposal of failed lamps do not cause environmental pollution, unlike for fluorescent lamps, in which mercury vapor exists.

Conclusion

Among the advantages of light sources based on auto emission are also low power consumption, high performance, small size and weight, high radiation resistance, low material consumption and low manufacturing costs.

The listed advantages of emitters with autocathode allow using them effectively in the above-mentioned applications and other fields of engineering. A cathodoluminescent light source makes it possible to obtain visible radiation, the spectral composition of which is favorable for visual perception and does not cause such eye fatigue as most known light sources.

References

1. Sheshin E.P. *Struktura poverhnosti i avtojemissionnye svojstva uglerodnyh materialov* [Structure of the surface and autoemission properties of carbon materials]. M.; MFTI, 1967, 124 p. (Rus)

2. Silva S.R.P., Forrest R.D., Khan R.U. Tailiring of the field emission properties of hydrogenated amorphous carbon thin films by nitrogen incorporation and thermal annealing. *Diamond and Related Materials*. Science Direct, 2000, Vol. 9, Issue 3-9, pp. 1205-1208.

3. Kroto H.W., Heath J.R., O' rien S.C., Curl R.F., Smalley R.E. C60: Buckminsterfullerene. *Nature International Journal of Science*, 1985, Vol. 318, pp. 162. doi : 10.1038/318162a0

4. Iijima S. Herical microtubules of graphitic carbon. *Nature International Journal of Science*, 1991, Vol. 354, pp. 56. doi: 10.1038/354056a0

5. Bondarenko B.V., Makuha V.I., Rybakov Ju.L. et al. *Vlijanie sherohovatosti poverhnosti avtokatodov na ih jemissionnye harakteristiki* [Influence of surface roughness of autocathodes on their emission characteristics]. *Radiotehnika i jelektronika*. M.; MFTI, 1987, Vol. 32, pp. 2606-2610. (Rus)

6. Bondarenko B.V., Makuha V.I., Sheshin E.P. *Model' mikrorel'efa avtokatoda s razvitoj rabochej poverhnost'ju* [Model of the microrelief of the autocathode with a developed working surface]. *Fizicheskie javlenija v jelektropriborah*. M.; MFTI, 1986, pp. 18-21. (Rus)

7. Bondarenko B.V., Sheshin E.P. et al. *Issledovanie jerozii uglerodnyh avtokatodov v kamere REM* [Study of the erosion of carbon autocathodes in the REM chamber]. *Jelektronnaja tehnika*, 1986, Issue 4, pp. 8-12. (Rus)

8. Suvorov A.L., Sheshin E.P., Prostasenko V.V. *Mikrosherohovatye ploskie avtojemissionnye katody iz grafita* [Micro-rough flat field emission carbon-made cathodes]. *ZhTF*, 1996, Vol. 66, pp. 156-160. (Rus)

9. Bondarenko B.V., Il'in V.N., Sheshin E.P. *Jemissionnye harakteristiki avtokatodov iz plastin pirografita* [Emission characteristics of autocathodes from pyrographite plates]. *Jelektronnaja tehnika. SVCh jelektronika*, 1988, Vol. 1, pp. 34-38. (Rus)

10. Il'in V.N., Shomin D.A., Pogorelova V.I. *Avtojelektronnaja jemissija pirografita* [Auto-electronic emission of pyrographite.]. *Tezisy dokladov XX Vsesojuznoj konferencii po jemissionnoj jelektronike*, Keiv, 1987, Vol. 1, p. 235. (Rus)

11. Kosakovskaja Z.Ja, Chernozatonskij L.A., Fedorov E.A. *Nanovolokonnaja uglerodnaja struktura* [Nanofiber carbon structure]. *Pis'ma v ZhJeTF*, 1992, Vol. 56, Issue 1, pp. 26-30. (Rus)

12. Baturin A.S., Yeskin I.N., Trufanov A.I., Chadaev N.N., Sheshin E.P., Tchesov R.C. Electron gun with field emission cathode of carbon fiber bundle. *J. Vac. Sci. Technol*., 2003, Vol. 21, Issue 1, pp. 354–357. doi. 10.1116/1.1527596

13. Baker F.S., Osborn A.R., Williams J. Field emission from carbon fibers. *Nature International Journal of Science*, 1972, Vol. 239, pp. 96. doi: 10.1038/239096a0

14. Colin L. Field emission from carbon fibers. *Journal of Physics*, 1973, Vol. 6, pp. 105–114.

15. Elinson M.I., Vasil'ev G.F. *Avtojelektronnaja jemissija* [Autoelectronic emission]. M.: Gos. izd. fiz.-mat. lit., 1958, p. 274. (Rus)

16. Baturin A.S., Chadaev N.N., Sheshin E.P. et al. *Razrabotka lampy podsvetki dlja gidrokristallicheskih jekranov* [Development of a backlight for hydrocrystalline screens]. *Tezisy dokladov 9 NTK "Sovremennoe televidenie"*. M.: Nauka, 2001, pp. 21-23. (Rus)

17. Obraztsov A.N., Pavlovsky I.Yu., Volkov A.P. Prototype of Light Emitting Device with Thin Film Cold Cathode. *Proceedings of the 19th Int. Display Research Conference. Berlin*, 1999, pp. 229-231.

18. Arfaoni I., et al. Toward lighting devices and flat panel displays based on carbon nanotube field emitter. *IVESC Proc*, 2002, pp. 139.

19. Obraztsov A.N., Volkov A.P., Zakhidov A.A. et al. Field emission characteristics of nanostructured thin film carbon materials. *Applied Surface Science,* 2003,Vol. 215, pp. 214–221.

20. Guljaev Ju.V., Sinicyn N.I., Torgashov G.V. et al. *Avtojelektronnaja jemissija s uglerodnyh nanotrubnyh i nanoklasternyh plenok* [Autoelectronic emission from carbon nanotubes and nanoclusters]. *Radiotehnika i jelektronika*, 2003, Vol. 48, pp. 1399-1406. (Rus)

21. Sinicyn N.I., Guljaev Ju.V., Gluhova O.V. et al. *Issledovanie vozmozhnostej postroenija novyh vakuumnyh indikatorov i displeev na osnove uglerodnyh nanotrubnyh i nanoklasternyh avtokatodov* [Investigation of the possibilities of constructing new vacuum indicators and displays based on carbon nanotube and nanocluster autocathodes]. *Radiotehnika*, 2005, pp. 35-40. (Rus)

22. Guljaev Ju.V., Elesin V.F., Sinicyn N.I. et al. *Katodoljuminiscentnye istochniki sveta na osnove avtojelektronnoj jemissii: koncepcija prakticheskoj realizacii* [Cathodoluminescent light sources based on field emission: the concept of practical implementation]. *Svetotehnika*, 2000, pp. 10-14. (Rus)