ALT 12
Advanced Laser Technologies
2 – 6 September 2012, Thun, Switzerland

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c/o Bern University of Applied Sciences
Engineering and Information Technology
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DOI: 10.12684/alt.1.44

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Laser Structuring of Glass-Carbon for Improvement of Its Emitting Properties

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Abstract

Laser structuring as a stage of laser micromachining operations for glass-carbon plate processing is described. The operations of laser scribing, milling, cleaning, and marking were used for production of the field-emission multi-beam cathode preform. The operation of structuring was applied for the production of micropeaks on the surface of the cathode beams. Two different approaches were tested for laser structuring of the cathode beams: linear scanning and an overlapping blind holes technique. The nanopeaks are self-organized in the process of the structuring. As a result we obtained a field-emission cathode with a high density of current emission and a shorter technological route of production.

Introduction

The production and study of emitting structures is an important problem in many scientific centers. The main purpose of these researches is to enhance the manufacture of field-emission cathodes [1]. It was found out that a very promising substance for the manufacture of such devices is graphite with its modifications, in particular glass-carbon. This material has the valuable property of being able to self-organize nanostructures on its surface under laser action. These structures provide a high density of the emission current from the cathode. Such cathodes can be applied in all electrovacuum devices with a high density of electronic streams and a microsecond available time.

The manufacturing technique of glass-carbon field-emission cathodes with an average current density from the surface of 1 A/cm^2 is known. This processing technique [2] contains a long, complicated technological route including photolithography, thermochemical pickling in a hydrogen medium with a metal catalytic agent, ionic-plasma taper etching, electric spark machining, and operations for careful superficial cleaning of the glass-carbon. Such a complicated route impedes the production development of field-emission cathodes. In addition to the long manufacturing route, the described technology pollutes the glass-carbon surface with metal catalyst traces (as shown by the LIBS study [3]).

Some researches were carried out on glass-carbon structuring [4] and on the use of carbon nanotubes or nanoclasters as elements of emitting structures of field-emission cathodes [5–7]. Such cathodes have been proven to work fairly well in experimental flat-panel displays and light devices where a high density of current is not required and a low level of electric field strength is enough for emission.

The above mentioned papers described the manufacture of carbon structures with emitting properties without reviewing the features of field-emission as a technological process in real cathode assembly. In this paper the authors consider laser structuring as a stage in the manufacturing cycle of glass-carbon field-emission cathodes. Different approaches for the laser structuring of the cathode beam’s surface and their effect on the emission characteristics of the cathodes are described.

Method

Developers of field-emission cathodes usually choose the commercial brand of glass-carbon SU-2000. This material is treated well by laser radiation. It has excellent absorption capacity at 1064 nm wavelength, which is the most characteristic of the process equipment.

Testing of the modes of structuring was carried out with commercial and original Q-switched Nd:YAG laser systems having 1064 nm wavelength and nanosecond pulse duration.

The original structuring of the surface was implemented by linear scanning. Parallel and perpendicular lines with a choice of the minimum distance between them were engraved on the surface. The density of peaks on the surface was determined by the number of grid lines. At the intersections of the lines there were long grooves in the direction in which the last lines were patterned (Figure 1a). The next technological solution was the formation of the surface structure by overlapping blind holes. The scheme is presented in Figure 1b.

In both cases, there is single-mode laser radiation; that is, the intensity distribution in the beam cross-section is close to Gaussian. As shown in Figure 1b, the overlapping blind holes technique allows the density of the emitting structures to be increased. If the number of peaks obtained by linear scanning over a certain area is N^2, then the number of peaks obtained by the second method is $N^2 + (N–1)^2$ in the same area.

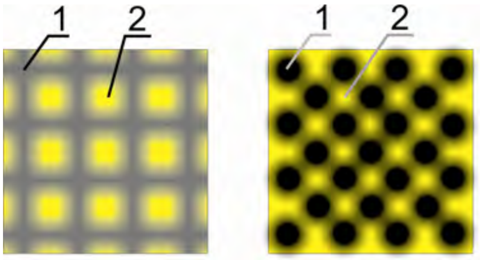

Figure 1. Schemes of the surface treatment. a) Linear scan. Dark lines labeled 1 are cut lines; yellow squares labeled 2 are peaks. b) Overlapping blind holes. Dark points labeled 1 are holes; yellow dots labeled 2 are peaks.

Results and Discussion

The appearance of the surface structure differs depending on the time of interaction, intensity, pulse repetition rate, and average laser power. The structures obtained with the diode-pumped Nd:YAG-laser setup, 50 ns pulse duration, 0.8 W average power, and 5 kHz pulse repetition rate have a height of 10 µm (Figure 2). The structures obtained with the same system but average power of 1.0 W and a pulse repetition rate of 10 kHz are 20 µm high (Figure 3).

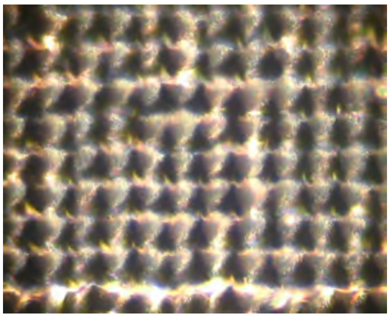

Figure 2. Microstructures on the surface of glass-carbon obtained by overlapping blind holes, with a peak base of 10 µm and a peak height of 10 µm

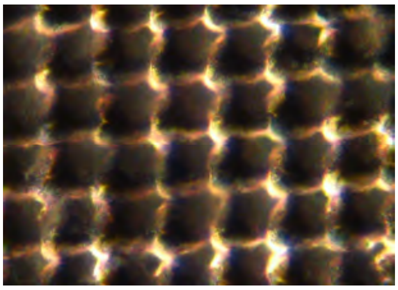

Figure 3. Microstructures on the surface of glass-carbon obtained by overlapping blind holes, with a peak base of 10 µm and a peak height of 20 µm

The packing density of the micropeak emitting structure is about 5×10^5–10^6 cm^{-2}. The peaks look like a four-sided pyramid with a base of 10 × 10 µm. Structuring of the 1 mm^2 surface area takes 8 seconds.

It was also found that there is a nanorelief on the tops of the micropeaks (Figure 4). It resembles a micropeak structure, but with an irregular distribution of the nanopeaks.

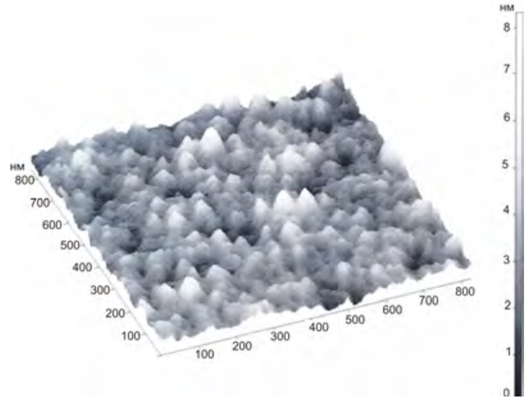

Figure 4. STM chart of the surface structure on top of the micropeaks

This nanorelief affects the distribution of the electrostatic field on the surface of the microscopic emitters and determines the field-emission characteristics of the cathode. The picture shown in Figure 4 was obtained with a scanning tunneling microscope (STM). The geometric nanorelief on the STM chart has the following dimensions: an average curvature radius of 0.5 nm, an average height of 7 nm, and an average step of the nanostructure of 80 nm. These dimensions correspond to a packing density of 1.5×10^{10} cm^{-2}.

Some principles for choosing the parameters needed for the manufacture of such structures have been clarified. The pulse duration should be about 10 to 50 ns, which is sufficient to avoid the growth of local stress and the heating of material. The average output power is 0.5–1.0 W; excess will lead to a decrease in the stability of the structures' distribution and to precipitation of carbon deposit on the surface. The pulse repetition rate is 5–12 kHz. The speed of the beam is 10 mm/s; the delay of the beam at one point is 20 to 30 ms.

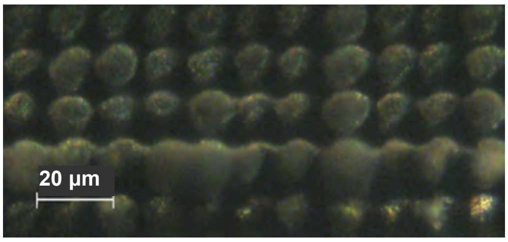

Figure 5. Needle-like microstructure on the surface of glass-carbon with excess energy input

If these parameters are exceeded, intensive evaporation of glass-carbon with a strong reverse deposition of vaporized material onto the treated surface takes place. The structure on the surface becomes irregular in both height and form (Figure 5). Peaks take the form of cylinders with a domed top; the height of the cylindrical needles varies from 20 to 40 μm and their diameter varies from 7 to 15 μm.

The 19-beam glass-carbon field-emission cathode with surface structures (Figure 6) was manufactured and tested. Measurements indicated that in pulse mode at an electric field strength of 6×10^5 V/cm a current density of about 10 A/cm^2 can be achieved.

Figure 6. Glass-carbon field-emission cathode with a base diameter of 3.2 mm and beam diameter of 250 μm

Conclusions

The results of the interaction of laser radiation with glass-carbon SU-2000 showed that the best method of microstructuring is an overlapping blind holes technique. The peaks obtained represent a four-sided pyramid with a height of 10 μm or more and a base of 10 × 10 μm. The packing density of the micropeak emitting structure is of the order of 10^5–10^6 cm^{-2}. Structuring of 1 mm^2 of surface area takes a few seconds.

A nanorelief with a structure close to periodic is detected on the top of the manufactured micropeaks. It is not clear how far and in what direction the emission intensity will change with increasing height of nanostructures.

The measured field-emission of a cathode with a microstructured surface of the beams is about 10 A/cm^2. We plan further experiments on real devices to clarify the maximal currents which the nanotips can withstand before being destroyed.

Acknowledgments

The work was supported by the Ministry of Education and Science of the Russian Federation, Project 14.B37.21.0746, by State Contract No. P488 (13.05.10) on equipment of the regional branch of CCU “Laser and Optical Processing Technique” (Volga region branch).

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