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Precision Processing of CVD Diamond Plates by Cu-Laser Irradiation

R. O. Buzhinskii[a], K. I. Zemskov[b], A. A. Isaev[b], A. V. Vlasov[a], V. G. Ral'chenko[a], and V. V. Savranskii[a]
[a] *Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, Moscow, 119991 Russia*
e-mail: savran@kapella.gpi.ru
[b] *Lebedev Physics Institute, Russian Academy of Sciences, Leninskii pr. 53, Moscow, 119991 Russia*

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Abstract—The chemical vapor deposition (CVD) technique is applied for synthesizing diamond films and plates of large size (~100 mm) and high quality. In the given work, we consider one of the diamond-structure dimensional processing and microprocessing methods based on the application of a Cu laser, whose irradiation can be focused to a small spot and also used for the intensification of the image brightness in an optical system, which is able to process ~10^6 points of an object for one (~10 ns) or a few pulses. The characteristics of processed surfaces of polycrystalline diamond films and plates are given.

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INTRODUCTION

Diamond and diamond-based structures find increasing application in modern technologies [1]. As known, the mechanical processing of diamond is difficult. The most efficient methods of polycrystalline diamond processing are connected with the application of laser techniques [2].

Here, we consider the possibility of applying a pulsed gas-discharge Cu laser for microprocessing of polycrystalline diamond plates synthesized in microwave plasma. Interest in its application in the microprocessing processes is connected with that, besides the conventional methods of object point-by-point processing by a focused laser beam, the active medium of a Cu laser in the scheme of a laser projection microscope conjugated with a resonator [3] creates specified high light power density distributions, which are sufficient for the object processing, over the system field of view [4].

EXPERIMENTAL EQUIPMENT

The conceptual scheme of experimental equipment for the processing of diamond plates and the registration of processed surface images intensified in their brightness is shown in Fig. 1. The scheme of a laser projection microscope with a feedback was used [4]. The active Cu-laser medium with an average power of ~3 W in the lasing mode [5, 6] was used as an intensifier of image brightness.

The active-medium superluminescence is directed through the objective *3* onto sample *2* (diamond plate in our case) placed on computer-controlled *X*–*Y*–*Z* coordinate table *1*. After being reflected and scattered by the sample, light is further gathered by the same objective and intensified during a single pass through the active medium. On leaving the active medium, the laser radiation falls on quartz wedge *5*, where it is split into two beams. On screen *8*, an image formed in the light reflected from the wedge is registered by a digital camera and transmitted to a computer. The linearity of the camera work was provided by the system of filters *7*.

After passing through the wedge, the light beam forms a magnified object image on the surface of spherical mirror *10* placed at the distance equal to its curvature radius from the entrance pupil (microobjective). Consequently, the laser beam is formed between the object optically conjugated with mirror *10* with minimal losses in the system. At that, diaphragm *9* placed near the surface of mirror *10* can form the distribution of this beam intensity over the object surface and, consequently, determiine the shape of the processed object area. Such a system was proposed in [4] for processing objects by specified distributions of laser irradiation intensity. The linear image magnifications were 400–2500, whereas the system objective visible magnification was changed from 12.5× to 100×.

EXPERIMENTAL TECHNIQUE

In the above-described scheme, the microprocessing of 100-μm-thick and 53-mm-diameter diamond plates was usually conducted with the use of focused Cu-laser irradiation and the 12.5× objective. The average laser power was >3 W, at which the visual field in the scheme of a laser projection microscope was ~0.5 mm, the focusing spot diameter was ~7 μm in the case of point-by-point processing, and the laser worked with a resonator consisting of plane mirrors.

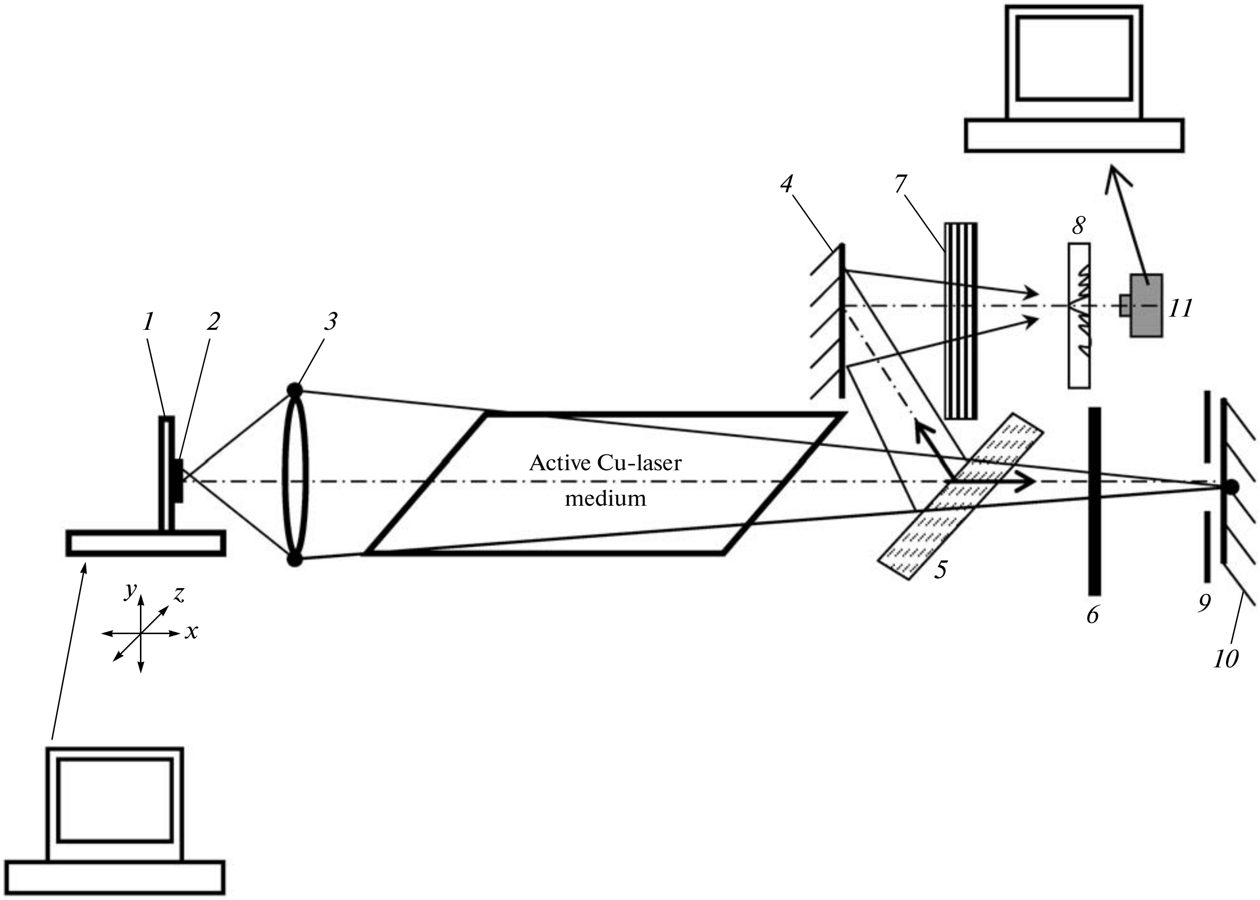

Fig. 1. Optical scheme of a laser projection microscope: (*1*) electromechanical coordinate table, (*2*) sample, (*3*) objective, (*4*) mirror, (*5*) quarts wedge, (*6*) opticomechanical curtain shutter, (*7*) system of filters, (*8*) semitransparent screen, (*9*) diaphragm, (*10*) spherical mirror, and (*11*) digital photo camera.

The microprocessing was conducted on the substrate and growth sides of samples. On the smooth (substrate) side, grooves ~20 μm in width and ~10 μm in depth were slotted by focused laser irradiation (Fig. 2). After laser processing, the samples were annealed in air at a temperature $T = 580°C$ for 30 min. The annealing promoted the elimination of the layer formed due to the graphitization of the diamond film under the action of laser irradiation (Fig. 3).

On the same side of the diamond plate, we drilled a series of blind holes at different durations of laser beam action on the sample (Fig. 4).

RAMAN SCATTERING AND INTERFEROMETRY INVESTIGATIONS

The structural analysis of carbon coatings was conducted with the use of Raman spectroscopy. The Raman scattering (RS) spectra were taken for the unprocessed, Cu-laser processed unannealed, and annealed parts of the diamond plate. The Raman scattering spectra are shown in Fig. 5.

A large diamond peak and a small smeared graphite peak are present in the spectrum of the unprocessed diamond plate. In the spectrum of the Cu-laser processed unannealed part of the sample, the intensity of the diamond peak is considerably lower due to the presence of a modified nondiamond inclusion absorbing the radiation of an Ar^+ laser used as an irradiation source in the Raman scattering experiments. After annealing in air, the intensity of the diamond peak increases but does not reach the value obtained for the unprocessed sample. This can be explained by the diamond inclusions not being eliminated completely.

By measuring the holes drilled in the diamond plate on a white-light interferometer, we obtained the dependence of the processing depth on the time of focused laser beam action on the diamond plate surface (Fig. 6).

As is seen from Fig. 6, at a time <2 s, the processing speed is rather high (~30 μm/s). As the time of action of the focused laser beam grows, the processing speed drops to 1.5 μm/s; at a time >4 s, the processing depth changes slightly, attaining 15 μm at the time >10 s. Such a type of dependence is caused, probably, by sev-

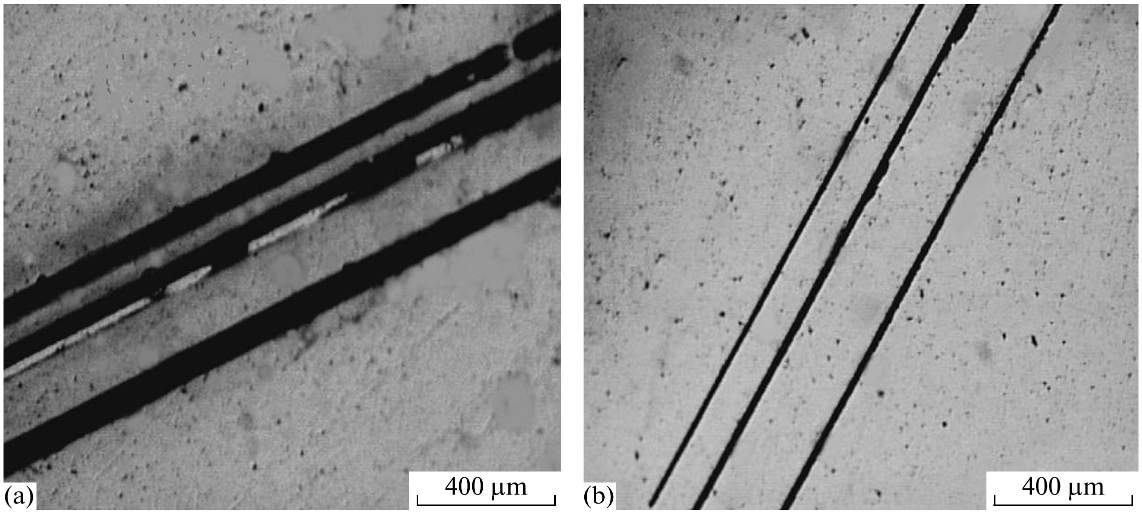

Fig. 2. Grooves slotted on the substrate side of a plate (a) before annealing, (b) after annealing. The scanning velocity is 63 μm/s, the diameter of processing spot is 10 μm, the depths of upper, middle, and lower grooves are 5, 8, and 6 μm, respectively.

eral reasons: the reduction in the power density due to the defocusing of the laser beam, the increase in the surface of the absorbing graphitized crater walls, and the absorption in the volume inside a crater. As the crater depth increases, the irradiated area grows proportionally to the squared depth. The irradiation dose necessary for the material ablation is proportional to the time of action and inversely proportional to the irradiated area. Consequently, the processing depth is proportional to the square root of the time. The dependence in Fig. 6 is in good qualitative agreement with this evaluation at a time >2 s. At lower times the presence of focused beam waist and other reasons, evidently, should be taken into consideration.

CONCLUSIONS

(1) The microprocessing of the growth and substrate surfaces of CVD polycrystalline diamond plates by the Cu-laser irradiation with $\lambda = 511$ nm, the pulse duration ~15 ns, and the pulse repetition frequency of 10–12 kHz in the scheme of a laser projection microscope conjugated with a resonator was proposed and realized experimentally.

(2) The effective ablation etching is completely provided at an average laser irradiation power of ~3 W at the expense of the sharp focusing of radiation with a small divergence angle of 1 mrad and due to the high linear magnification of topography projected onto the plate in the system of a laser projection microscope.

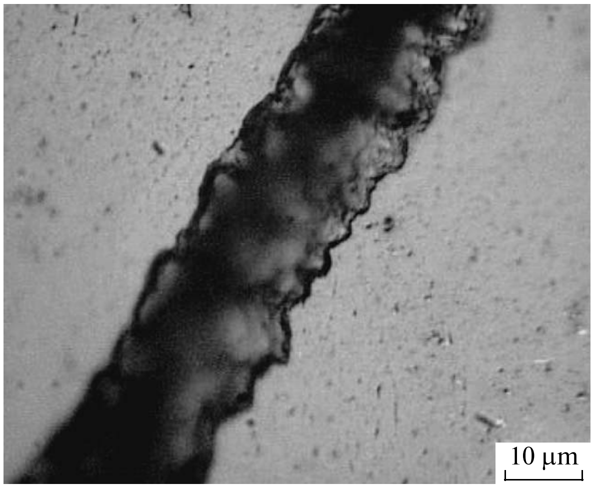

Fig. 3. Magnified image of a groove after annealing.

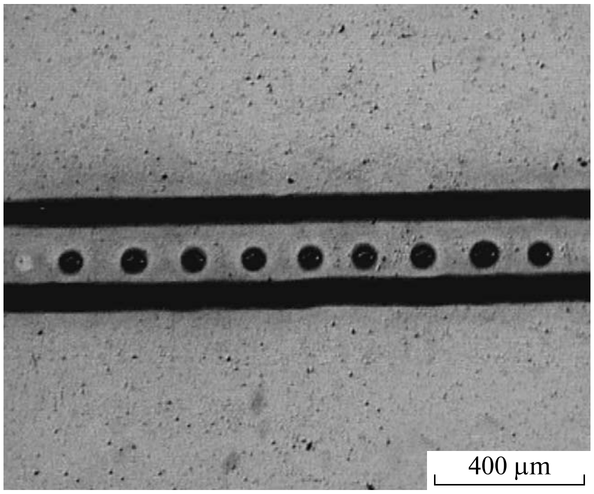

Fig. 4. Series of blind holes on the smooth (substrate) side of a plate, the processing time increases from left to right.

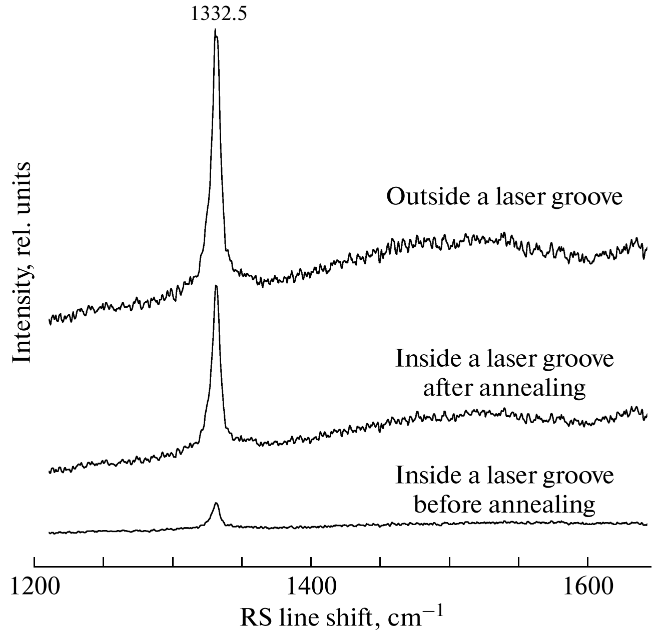

Fig. 5. Raman spectra for the diamond plate processed by the Cu laser. Scattering was excited by 514.5 nm Ar^+-laser irradiation focused onto a spot with a diameter of ~2 μm on the sample surface. The diamond plate was annealed at $T = 580$°C in air.

(3) Systems of microgrooves ~10 μm in width and holes and craters with diameters from 20 to 300 μm were created on the diamond plate surfaces. It was shown that only the characteristics of an optical system restricted radically the achievable processing precision. In experiments, the minimal characteristic dimensions of processed areas were generally determined by an insufficient rigidity of the equipment, in particular, the electromechanical positioner.

(4) The dependence of the ablation rate on the time of laser irradiation action was determined experimentally for the example of drilling microholes. The maximal hole drilling velocity of ~30 μm/s was reached at the beginning of the process. At long times of processing, the crater depth attained saturation (at ~15 μm).

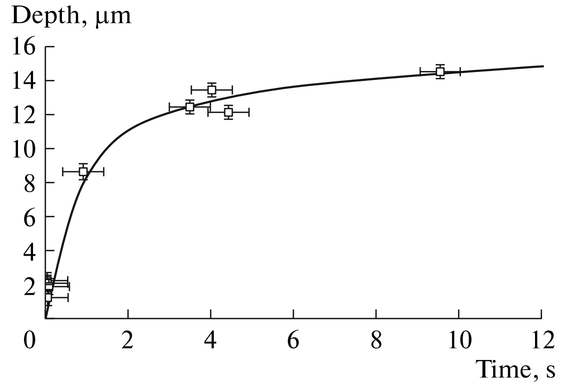

Fig. 6. Dependence of the hole depth on the time of laser irradiation action on the sample.

(5) The investigation of the material structure and composition in the processed area permitted optimization of the conditions of plate annealing in air to eliminate the graphite phase formed in the process of laser action.

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