Thermochemical processes of laser-matter interaction as a mean for creating quasi-one-dimensional nanomaterials

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•Abstract

Possibilities and features of thermochemical processes of interaction of powerful laser radiation with matter and optical systems for control of spatial distribution of beam intensity are described. Laser beams possess good focusing capabilities and provide the possibility to perform chemical reactions, including metal oxidation, locally and with high spatial resolution. With the use of laser beams with frequency modulation, a synergistic effect between the laser heat actions and the vibrations induced by the laser pulses is created. Thus, the coefficient of diffusion increases considerably as result of the nonstationary strain-stress state of the material. The synthesis of ZnO/Cu semiconductor-metal nanocomposite on the surface of brass samples is described. As a result of pulse-periodic laser treatment, anisotropic quasi-one-dimensional structures - zinc oxide nanowires - are formed on the material surface, i.e. on the conductive metal substrate. By using free-form diffractive optics to shape the laser beam, it is possible to control the chemical processes on the material surface. The resulting material structures are promising for sensor applications due to the sensitivity of ZnO to various chemical agents, biocompatibility, and the possibility of modifying it by various methods.

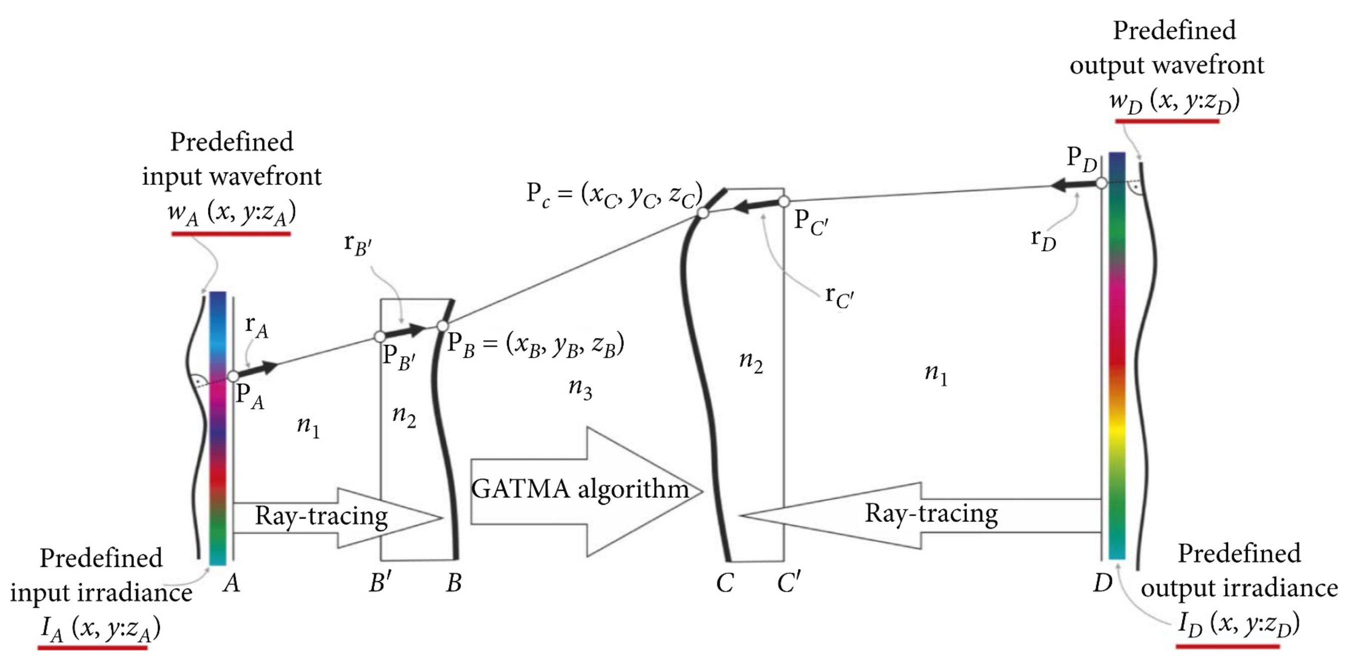

Figure 1. Statement of the calculation task for a beam shaper with two plano-freeform lenses [1].

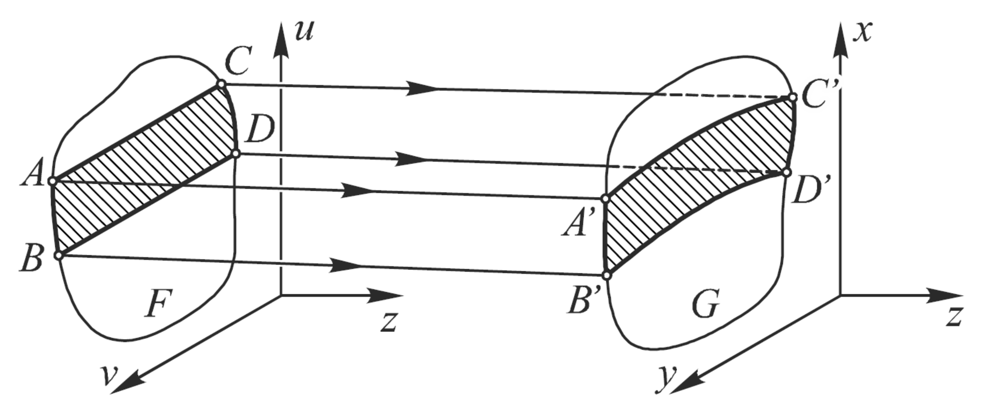

Figure 2. Schematic representation of the problem statement of focusing into a two-dimensional area [2].

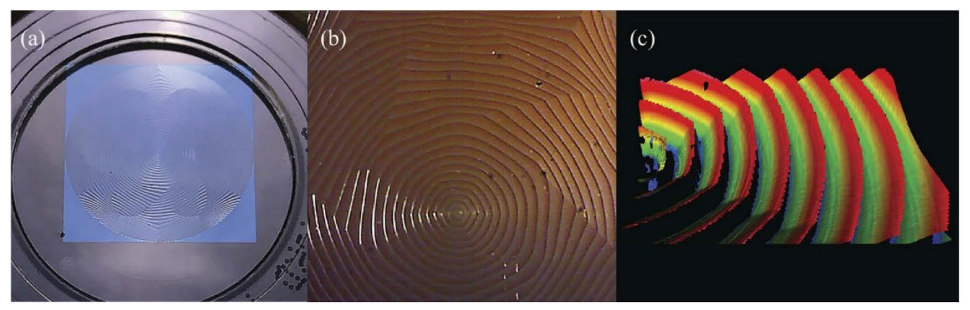

Figure 3. Photo of the produced diffractive optical element (a), image of the microrelief of the central part of the optical element obtained by an optical microscope (b), and microrelief of the central part of the diffractive optical element measured on a NewView 7300 interferometer (c) [3].

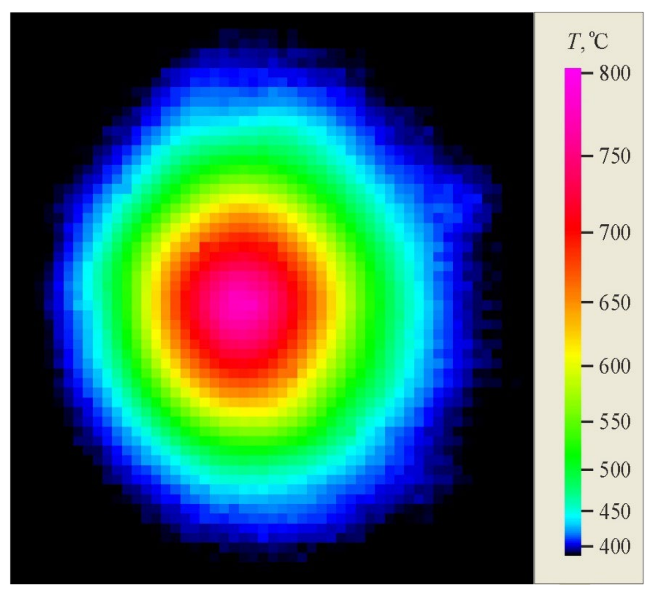

Figure 4. Temperature field in the sample as a result of laser irradiation [4].

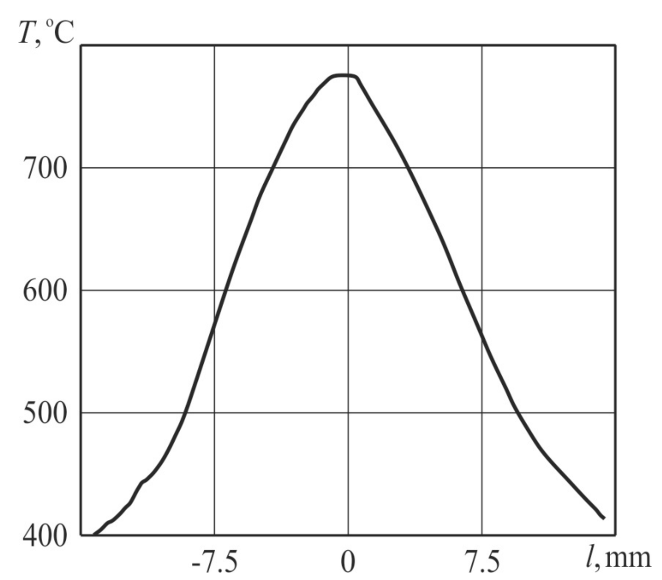

Figure 5. Temperature distribution in the central region of the sample [4].

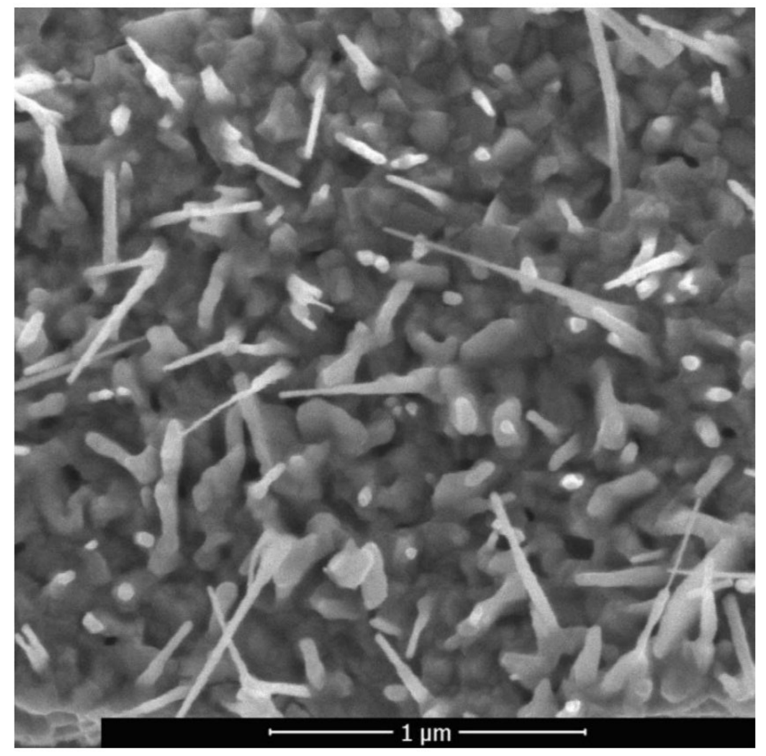

Figure 6. ZnO nanowires that formed on the surface brass by laser irradiaction [4].

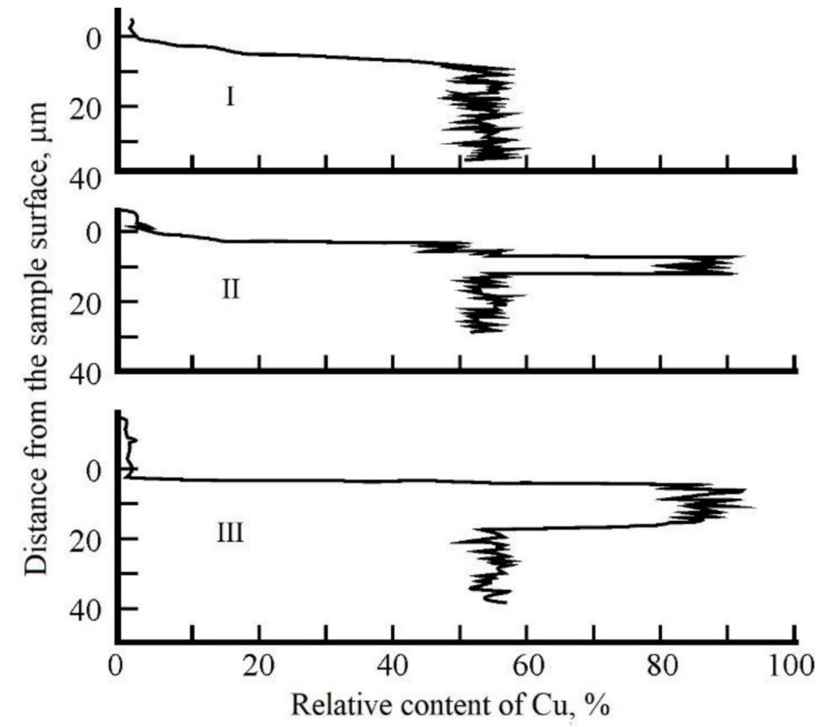

Figure 7. Chemical composition near the surface of copper-zinc alloy samples in areas: I - not subjected to laser irradiation; II - on the periphery; III - in the centre of the heat affected area after laser exposure [4].

•Conclusion

The use of laser beams with frequency modulation has demonstrated that the synergistic effect between the laser heat actions and the vibrations induced by the laser pulses takes place, mainly in the sound frequency range, can significantly increase the diffusion coefficient in the materials to be treated. The possibilities of enhancing the diffusion processes that are stimulated by vibrations induced by the laser pulses in metallic materials have been determined.

The synthesis of ZnO/Cu semiconductor-metal nanocomposite on the surface of brass samples is described. When the brass foils are heated in the air by pulse-periodic laser irradiation, the surface oxidation of the material is intensified. The formation of a lemon-yellow oxide coating was observed on the surface of the brass, which with increasing laser treatment time changed to a whitish-grey color that is typical for zinc oxide, and consisted from elongated needle-like crystals. It was found that the proportion of zinc among the metallic elements on the surface reached 99 %. The ZnO formation is preferable due to the higher oxidation rate of zinc than of copper, zinc diffusion to the surface takes place. Surface atoms tend to oxidize since they form a free surface compared to the atoms in the core mass of the material. Therefore, atoms on the surface easily form compounds to the air oxygen, absorbing it. Zinc diffusing from the inner volume on the surface will react to oxygen.

The morphology of ZnO nanostructures is sensitive as much to the temperature increase as to the local concentration of zinc, which is unevenly distributed in the alloy. The increase of temperature intensifies the diffusion and provides a greater inflow of zinc. This leads to the formation of longer nanowires; high temperature promotes the growth of lateral and branched ZnO crystals. After reaching a specific length, the growth of the nanowires slows down due to the reduced transport efficiency of the zinc to the apex. As a result of laser irradiation, anisotropic quasi-one-dimensional structures - zinc oxide nanowires - are formed on the material surface, i.e. on the conductive metal substrate. The resulting material structures are promising for sensor applications due to the sensitivity of ZnO to various chemical agents, biocompatibility, and the possibility of modifying it by various methods.

Preventing thermochemical instability is a key goal in controlling the laser thermochemical processes in general, including the formation of quasi-one-dimensional nanostructured metal oxides. Such instability lies in a positive feedback in the system, which causes the oxidation reaction to accelerate. By redistributing the energy/power of laser beam, i.e. changing the amount of absorbed energy, it is possible to control the thermochemical processes taking place. Improvement of laser beam shaping systems based on free-form diffractive optics opens up the possibility of controlling thermochemical processes by achieving the desired predetermined redistribution of energy density.

Based on the achieved results, new photonic technologies aimed at obtaining quasi-one-dimensional nanostructured oxide-metallic materials on conductive substrates with the possibility of controlling the morphology of such structures are created. The problem of providing the ability to control the thermochemical reaction in the laser irradiation area can be successfully solved by shaping the laser beam by optical systems that contain elements of free-form diffractive optics.

•References

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