Use of a high-current relativistic electron beam for structural and chemical transformations

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Experiments on the excitation of intense shock waves using a self-focused high-current relativistic electron beam (REB) are described. It is shown that by putting boron nitride or graphite in the accelerator focal spot there is a partial (within limits of $\lesssim 10\%$) transformation of the hexagonal *BN* and graphite to a finely-dispersed diamond phase. The possibilities of using REB for chemical syntheses are discussed.

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In the course of self-focusing of a relativistic electron beam (REB) in a diode for modern pulsed high-current accelerators, a power density exceeding 10^{12} W/cm^2[1,2] is reached in the focal spot on the anode. The energy generation during the pulse time ($\tau \leqslant 10^{-7}$ sec) for such a high power density leads to a thermal explosion of the anode surface. The vaporized substance which disperses at high speeds carries considerable momentum, leading to strong shock waves in the material being studied. In experiments carried out on the Kal'mar accelerator it was shown that by using an aluminum anode, energy equal to 2.5 kJ is generated at the focal spot with an area of 2 mm^2.[3] Since the average depth of penetration of the electron beam into the target is 0.5 mm (in these experiments the electron energy is 0.5 MeV), the volume energy density ω reaches 2.5×10^6 J/cm^3. Knowing the volume energy density, it is possible to find the pressure P of the plasma formed at the focal spot from the following equation:

$$P = \omega(\gamma_{\rm eff} - 1) .$$

Assuming that in our case the ratio of the specific heats is $\gamma_{\rm eff} = 1.2$, according to the calculations in Ref. 4, we find that $P \leqslant 5 \times 10^6$ bar. Taking into account the expansion of the plasma cloud in a vacuum, the value of the actual pressure P is reduced to 2.5 M bar.

The existence of high pressures in the focal spot of the high-current REB of the Kal'mar accelerator is confirmed by metallographic studies of copper samples subjected to a single-stage REB. The hardening of the copper and the presence of multiple sliding bands in the irradiated sample was studied at a distance of 4.5 mm from the focus, and the pressures were then recalculated. This estimate also agrees with the numerical calculations of Widner and Thompson[5] for an REB with similar parameters.

The use of shock waves generated by the explosion or by the high-speed impact of a solid body has turned out to be extremely fruitful in science[6] and technology.[7] The pressures and temperatures realized in REB generators have a special characteristic: on time of the high pressure is an order of magnitude smaller and, as a rule, the temperature is two orders of magnitude larger. It may be hoped to find specific regions

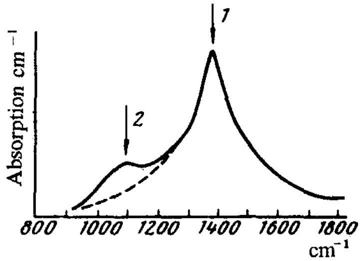

FIG. 1. *IR* absorption spectrum for boron nitride irradiated by an REB: 1-maximum for graphite-like modifications; 2-maximum for diamond-like modifications.

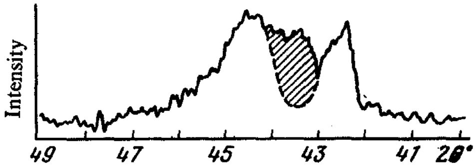

FIG. 2. Portion of a diffractogram for a mixture of 10% graphite and 90% Pb irradiated by an REB; the shaded region corresponds to the diamond phase.

for their application to solid state physical chemistry and materials technology. The achievement of high pressures using REB opens up wide possibilities for studying the behavior of a substance under extreme conditions. In particular, the high thermodynamic parameters obtained in this way may turn out to be useful in carrying out structural and chemical transformations. Thus, it was found that by coupling an REB to hexagonal (graphite-like) *BN* located at the focal spot of the Kal'mer accelerator, there is a partial ($\leqslant$10%) conversion of the initial structure to diamond (a type of wurtzite). This may be seen in the *IR* absorption spectrum of the irradiated material which is shown in Fig. 1.

The coupling of the REB to graphite also causes structural changes. As shown by the x-ray data, there is a partial ($\leqslant$10%) conversion of the graphite structure to a hexagonal diamond phase, which is indicated by the portion of the diffractogram shown in Fig. 2.

It should be noted, however, that the phase transition occurs significantly only for the case where a mixture of graphite and metallic "coolers" (Cu, Pb) is subjected to irradiation, or if the graphite sample following impact disperses into a special container. As a result of these methods, the annealing effect of the high temperature is successfully reduced. At the same time, the short-lived ($\leqslant 10^{-7}$ sec) effect of the high pressure leads to the formation of a very finely-dispersed diamond phase, which in an x-ray plate leads to a larger change in the area of the graphite bands than for the peak of a natural diamond band. Microscopic study of graphite samples irradiated by an REB showed that the diamond phase is included in the original phase in tesselated fashion, while the indices of refraction for the irradiated materials in this case are $\geqslant$2.2.

The combined effect of high pressures and temperatures may turn out to be quite promising for chemical synthesis. The reaction $CuBr_2 + Cu \rightarrow CuBr$ proceeds with 100% efficiency. Iron and copper carbides usually requiring prolonged heating are easily formed. This method may apparently turn out to be most promising for chemical interactions which require for their initiation the overcoming of large potential barriers (activation energies).

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