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URGENT COMMUNICATION

X-Ray Radiation in Self-Propagating High-Temperature Synthesis Processes

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Emission effects of heterogeneous combustion in the region of ionization radiation are studied. By an example of a Ti–B powder system, it is demonstrated that the processes of self-propagating high-temperature synthesis in the thermal explosion regime is accompanied by "soft" X-ray radiation with the quantum energy estimated as ≈5 keV.

Key words: heterogeneous combustion, X-ray radiation.

INTRODUCTION

A specific feature of self-propagating high-temperature synthesis (SHS) is an elevated level of density of chemical energy dissipated by the reaction wave per unit time (more than 10^{13} W/m^3). In terms of this parameter, SHS exceeds gas flames by three or four orders of magnitude and approaches detonation phenomena. As was mentioned in [1, 2], combustion of Ni–Al, Ti–C, Mo–B, and other systems is accompanied by generation of a gas plasma with a high concentration of charged particles (up to 10^{22} m^{-3}), a flux of "hot" electrons with the energy spectrum up to 150 eV, radiofrequency radiation in the microwave range, and other nonequilibrium emission effects. The latter characterize dissipative phenomena in the system (exoemission of electrons and ions from the free surface of condensed phases, bremsstrahlung of plasma electrons, etc.) stimulated by the reaction process. It was demonstrated [3] that the thermal explosion of Ni–Al and Ti–B systems emits intense optical radiation in the ultraviolet range at 200–400 nm whose power is comparable with that of the thermal spectrum. Ultraviolet radiation occurs at the initial stages of the process during the time interval (up to 50 msec) close to the characteristic time of chemical conversion of the system. At further stages, the system emits the thermal spectrum only.

The present paper describes the analysis of the energy limits of SHS emission effects in the range of ionization radiation.

MATERIALS AND METHODS OF RESEARCH

A Ti–B powder system was studied. A mixture of titanium powder and amorphous black boron (98% purity) was prepared with a weight ratio Ti + 31.1% B. The particle size was within 60 μm (for Ti) and 1 μm (for B). To remove moisture and volatile admixtures, the species were first subjected to thermovacuum treatment at a temperature of 820 K (Ti) or 1120 K (B) and a pressure of 10^{-2} Pa. The mixture with a bulk density and a weight of 0.5 g was placed into a cylindrical quartz cavity 18 mm in diameter, which was located on the surface of molybdenum foil. The SHS re-

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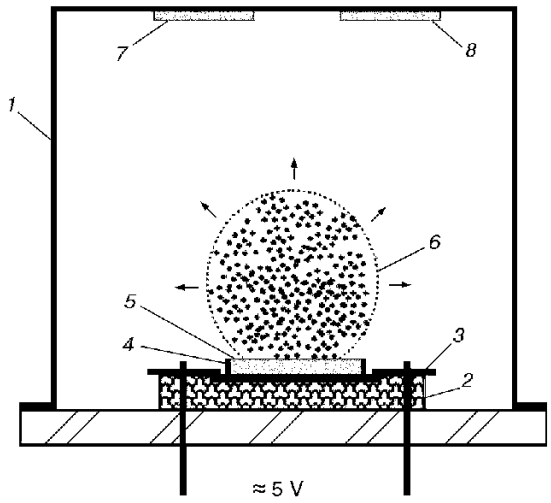

Fig. 1. Experimental arrangement: 1) vacuum chamber; 2) dielectric substrate; 3) molybdenum foil; 4) quartz cavity; 5) initial mixture; 6) cloud of the suspension; 7) dosimeter; 8) photographic assembly.

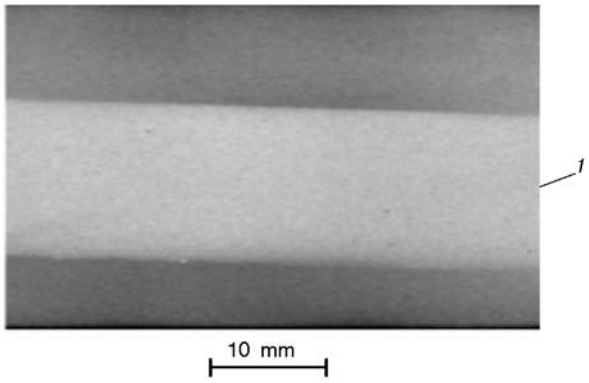

Fig. 2. Flare of the RF-3 photographic film by X-ray radiation induced by the thermal explosion in the Ti–B system (the region shaded by the absorbing plastic plate is indicated by 1).

action was initiated in a vacuum chamber in an argon medium at a pressure of 70–100 Pa by slow heating of the foil to a temperature of 1100–1200 K by electric current during 1–3 min. The reaction proceeded in the thermal explosion regime. A simplified scheme of chemical conversion of the mixture can be presented as $Ti + 2B \rightarrow TiB_2 + 293$ kJ/mole.

Ionization radiation (outside the optical range) was registered onto the RF-3 X-ray photographic film and also by an Arrow-Tech, Inc (Model 138) X-ray dosimeter. To prevent the action of optical radiation, the x-ray photographic film was placed into a light-impermeable envelope made of dense black paper. In some experiments, a plastic plate 120 μm thick was placed on the film surface to screen a certain part of the latter. The photographing assembly (film, absorbing plate, and envelope) and the dosimeter were placed in the upper part of the vacuum chamber at a distance of 25 cm above the surface of the powder mixture sample (Fig. 1). The methods for X-ray measurements were previously tested in [4, 5].

RESULTS AND DISCUSSION

Owing to the flow of gaseous products released (gasification of admixtures, partial evaporation of the main species), the thermal explosion leads to formation of an emitting cloud of the suspension. The cloud has a radius up to 20 cm and consists of droplets of the condensed product 10–200 μm in size and an ionized gas. Based on the results of [6], the droplets seem to be formed through coalescence of the melted initial particles of the mixture at the initial stage of the reaction with subsequent evolution of Ti–B chemical interaction inside the droplets at the stage of cloud formation. The integral time of the process recorded on the basis of optical emission was shorter that 0.1 sec.

The research showed that the reaction process is accompanied by emission in the X-ray range. The total exposure dose of radiation measured by the dosimeter reached 10 mR in a series of 24 explosions. The radiation doses in individual explosions are substantially different and can reach 2.5 mR. Note that the recorded exposure dose was the same if the dosimeter was protected from X-ray radiation by an aluminum film 3 μm thick.

The character of film flare testifies to the presence of "soft" X-ray radiation. As is seen from Fig. 2, radiation penetrates through the envelope 80 μm thick, but is retained by a double layer of paper (80 μm) and absorbing plastic plate (120 μm). Here the region of film blackening is restricted by the contours of the plastic plate located on the film. If an envelope 130 μm thick was used, no film flare was recorded. The estimates performed in [5] showed that the film placed into a black paper envelope 95 μm thick was expected to be flare under the action of X-ray quanta with an energy of $\approx$5 keV. Taking into account that radiation absorption obeys the known relation $J = J_0 e^{-\mu t}$ (J_0 and J are the radiation intensities before and after its passage through the layer of the substance, t is the layer thickness, and μ is the linear coefficient of absorption), we can evaluate the energy of X-ray quanta. To ensure flare of a film placed into an envelope 80 μm thick, the quantum

energy should be 3–4 keV; for the envelope thickness of 130 μm, the corresponding value should exceed 7 keV; hence, the level of quantum energy responsible for the film flare effect observed should be ≈5 keV.

The data obtained do not yet offer a clear idea about the mechanism of the emergence of the X-ray radiation observed. As the chemical energy release in the examined region is lower than 1 eV per atom on the average, a necessary condition for generation of X-ray quanta with an energy of 5 keV is the presence of collective effects of excitation with participation of multiatomic structures of condensed systems (e.g., clusters or nuclei). Radiation can be emitted directly from the free surface of the droplets in the suspension cloud in the course of the chemical reaction or result from deceleration of high-energy free electrons of the plasma, which are accelerated in regions of local amplification of the electric field. Elucidation of the nature of ionization radiation of the SHS process requires additional research to be performed.

CONCLUSIONS

The presence of X-ray radiation in the SHS process was established by an example of combustion of the Ti–B powder system. The estimated energy of radiation quanta is 5 keV.

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