DIRECTED SELF-PROPAGATING HIGH-TEMPERATURE SYNTHESIS OF A SERIES OF EXPLOSION-EMISSIVE METALLOCERAMIC MATERIALS

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The problem of production of materials for electron emitters with specified characteristics using the method of self-propagating high-temperature synthesis has been examined. The conditions under which this process occurs in a reagent mixture containing components that interact by two scheme have been analyzed by thermodynamic calculations of adiabatic temperature. Some laws of combustion have been studied experimentally. A satisfactory agreement has been reached between the experimental and calculated data. The possibility of producing materials with a reinforcing frame has been considered.

The creation of materials with novel characteristics is essential in various areas of science and engineering. This paper reports the experimental results obtained for a class of multicomponent materials based on lanthanum hexaboride LaB$_6$ by the method of self-propagating high-temperature synthesis (SHS). One of the main advantages of this method is that it is possible to obtain materials with specified characteristics. The latter are prescribed to produce explosion-emissive cathodes for high-current electron accelerators [1]. Thus, the main stages of our study are the following:

- substantiation of the element composition that provides the required emission characteristics;
- consideration of the possibility in principle of combustion of selected systems on the basis of preliminary thermodynamic analysis, and (if combustion is possible) optimization of the determining parameters and conditions for synthesis;
- performance of laboratory experiments to obtain materials based on the results of thermodynamic analysis.

JUSTIFICATION OF ELEMENTAL COMPOSITION

Lanthanum hexaboride LaB$_6$ is known to be characterized by a considerable autoemission current, and the presence in the surface layer of a lanthanum-atom emitter made of this compound makes it possible to decrease considerably the work function. The compounds LaB$_6$–Me(IV)B$_2$, where Me(IV) are group-IV metals of the periodic system (Ti, Zr, Hf) [2], also show rather high thermoemissive characteristics [2].

It is assumed then that emitters made of a LaB$_6$–Me(IV)B$_2$ material will have a number of advantages over conventional explosion-emissive emitters.

As an example, consider the production of the emissive LaB$_6$–TiB$_2$-based material. The possibility of realizing SHS in the system in question depends on the following reactions [3]:

\[
\text{TiO}_2 + \frac{10}{3} \text{B} \rightarrow \text{TiB}_2 + \frac{2}{3} \text{B}_2\text{O}_3,
\]  

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As shown in [4], it is rather difficult to determine the critical combustion conditions for each concrete case, because these strongly depend on many varying factors (including geometrical and thermophysical). In this case, the conditions for system combustion can be determined by thermodynamic calculations of adiabatic temperatures $T_{ad}$:

- $T_{ad} < 1500$ K — no combustion;
- $T_{ad} > 2000$ K — the system always burns;
- $1500$ K $< T_{ad} < 2000$ K — further studies are necessary.

### THERMODYNAMIC ANALYSIS OF REACTIONS IN A COMPLEX MIXTURE OF REAGENTS

The adiabatic temperatures of a complex system of reagents interacting via schemes (1) and (2) have been calculated by technique [3], in which $T_{ad}$ was determined using equality of the enthalpies of both the original substances at the initial temperature $T_0$ and the final products at temperature $T_{ad}$. Thus, the total heat release of the reactions goes to heating of the combustion products from $T_0$ to $T_{ad}$. The calculations were performed for the case of complete reagent transformation. Hence

$$Q = \int_{T_0}^{T_{ad}} c_{miz}(T) dT,$$

where $c_{miz}(T)$ is the temperature dependence of the LaB$_6$–TiB$_2$ mixture heat capacity; $Q$ is the total heat effect of reactions (1) and (2). In accordance with the additivity rule, the mixture heat capacity consists of the capacities of the components involved.

The main difficulty in calculating the adiabatic temperatures is that of finding the temperature dependence of heat capacity $c(T)$. The experimental data available for the materials obtained are in many cases either incomplete or need extrapolation to higher temperatures. Since combustion is realized in the condensed phase, the heat capacity of the reaction products can be determined by the Debye model, according to which

$$c(T) = 9Nnk\left(\frac{T}{\Theta}\right)^3 \int_0^{\Theta/T} \frac{x^4e^x dx}{(e^x - 1)^2}.$$

Here $N$ is the number of substance molecules (atoms) [the measurement units of $N$ depend on those of the reaction thermal effect. For example, if the $Q$ value is given in J(cal)/g, $N$ is expressed in g$^{-1}$]; $n$ is the number of atoms in a molecule of the substance under study; $k$ is Boltzmann’s constant; $\Theta$ is the characteristic