

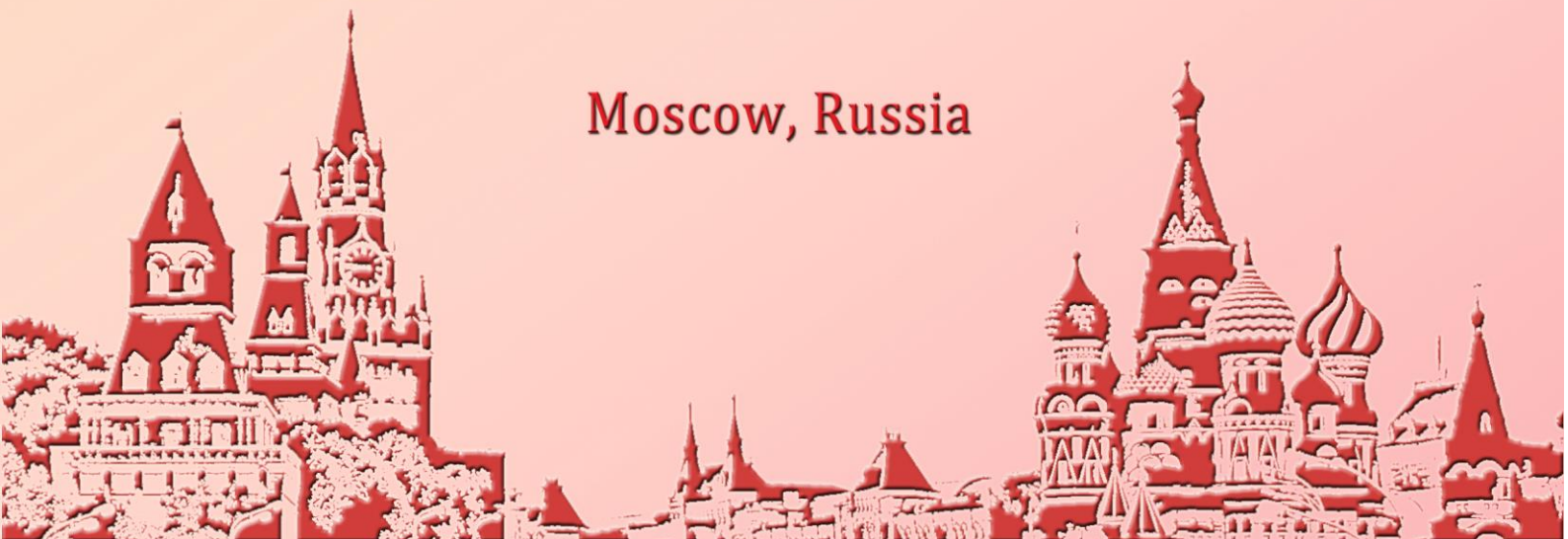
A graphic element for the SHS 2019 logo, featuring a vertical stack of horizontal bars in shades of orange and yellow, topped with a crown-like shape. A horizontal line extends from the top of this graphic to the right, ending above the text "SHS 2019".

# SHS 2019

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## SOLID-STATE REACTIONS IN Al-BASED MULTILAYER NANOSYSTEMS

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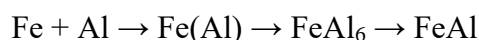
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The aim of this study was to establish a sequence of phases formed during the solid-state reaction in Al/Cu and Al/Fe bilayer nanosystems. The investigations were carried out by *in situ* electron diffraction, which allowed us to examine the phase composition variation directly during the solid-state reaction.

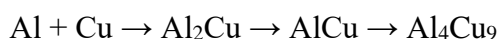
The Al/Cu and Al/Fe bilayer nanosystems were obtained by the method of electron beam evaporation in high vacuum with the help of a high vacuum installation MED-020 (Bal-Tec). The base vacuum was  $5 \times 10^{-5}$  Pa. The bilayer films with the thickness of 40–60 nm were obtained by the successive deposition of layers onto a substrate.

The microstructure and elemental composition of the nanosystems were examined by a JEOL JEM-2100 transmission electron microscope. The phase composition of the investigated samples was determined from electron diffraction patterns. The solid state reactions in Al/Cu and Al/Fe were initiated by thermal heating. The heating was performed directly in the JEM-2100 column using a Gatan heating holder. This method was successfully used to study the solid state reactions in Al/Pt [1], Cu/Au and Fe/Pd [2] bilayer nanosystems.

The solid-state reaction between Al and Fe nanolayers was detected at a temperature  $\approx 100^\circ\text{C}$ . The reaction starts from the formation of Fe(Al) – the solid solution of Al in  $\alpha$ -Fe. This is accompanied by the increase of the  $\alpha$ -Fe lattice constant (see Fig. 1). At  $\approx 400^\circ\text{C}$  there begins the formation of a FeAl<sub>6</sub> phase and at  $\approx 480^\circ\text{C}$  the formation of FeAl phase stars (Fig. 2), which corresponds to the atomic proportion of Fe and Al in the Al/Fe bilayer nanosystem under investigation (Al:Fe  $\approx 50:50$  at %). So, the following phase sequence was observed during the solid-state reaction in the Al/Fe nanosystem:



The beginning of the solid-state reaction between Al and Cu nanolayers was detected at  $\approx 90^\circ\text{C}$ . The reaction starts from the formation of Al<sub>2</sub>Cu phase, in accordance with the prediction of the effective heat of the formation rule [3]. The following phase sequence was observed during the solid-state reaction in the Al/Cu bilayer nanosystem:



The electron diffraction patterns obtained in the process of heating of the Al/Cu nanosystem were analyzed to determine the quantitative content of the phases formed during the solid-state reaction in the Al/Cu bilayer nanosystem (see Fig. 3).

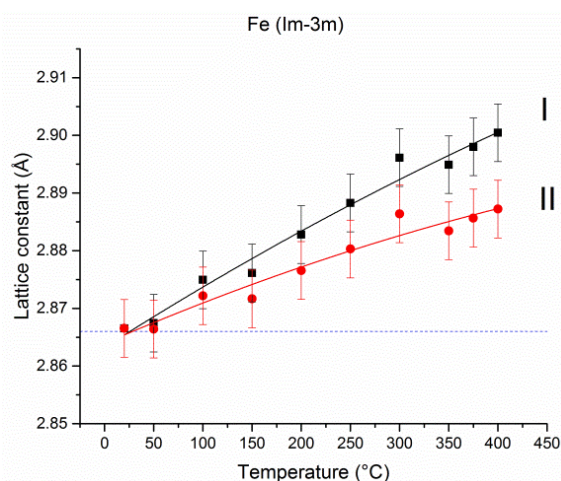


Fig. 1. The changing of  $\alpha$ -Fe lattice constant during the heating of Al/Fe (curve I – the experimental data; curve II – the data without contribution of thermal expansion).

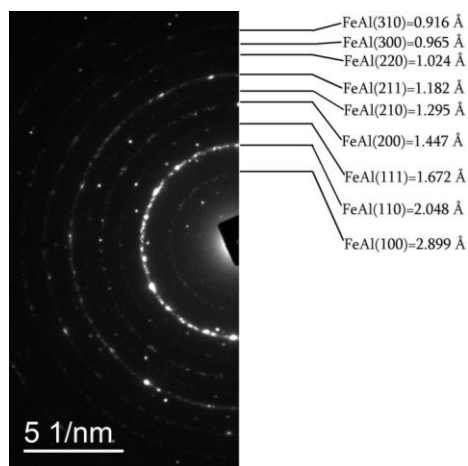


Fig. 2. Electron diffraction pattern obtained from Al/Fe at heating up to 650°C.

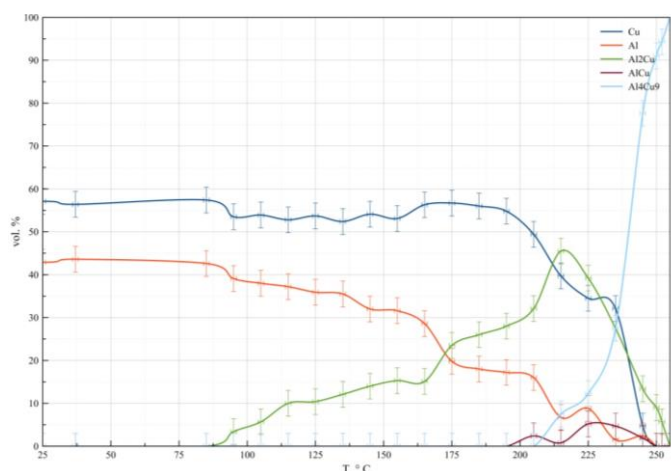


Fig. 3. Variation in the phase composition during the solid-state reaction in the Al/Cu bilayer nanosystem (vol %).

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