Time-Resolved Characterization of Metastability during Phase Transformations in Metallic Multilayers Induced by Ultrafast Heating

K. Woll[1)], M. Grapes[2)], T. Weihs[2)]

[1)] Institute of Applied Materials (IAM), Karlsruhe Institute of Technology (KIT), 76344 Eggenstein-Leopoldshafen, Germany

[2)] Department of Materials Science and Engineering, Johns Hopkins University, 38000 Baltimore, USA

Nanoscaled reactive multilayers define a class of materials for high-density chemical energy storage generating heat during ultrafast self-propagating reactions to intermetallic compounds. Reactive multilayers act as localized heat sources where heating and cooling occur in less than 1 s. Micro-joining at smallest scale with very limited thermal exposure represents an example. Beside their relevance in said applications reactive multilayers also serve as model materials for exploring irreversible phase transformations under non-equilibrium conditions. When slowly heated, experiments usually reveal a sequential transformation behavior. The ultrafast heating rates during self-propagating reactions of up to 10^7 K/s, however, impose a substantial constraint upon the phase sequence. In situ time-resolved experiments suggest the particular importance of the heating rate effect.

Very recent studies use a nanocalorimeter to heat multilayers with heating rates close to that of self-propagating reactions. Here, we report the results from a nanocalorimetric study of solid-state mixing in Ni/Al multilayers. Under ultrafast heating, we still identified a sequential transformation behavior. However, evidenced by the number of exothermic peaks during reaction, a significant change in the sequence is observed for the first time. We use analytical models and thermodynamic data to predict the first phase to nucleate as a function of heating rate. Though, up to now the identification of the nucleating phases and the experimental nucleation analysis remain open. For that purpose, we also discuss novel time-resolved synchrotron experiments enabling us to reveal simultaneously thermodynamic and structural information characterizing such and similar transformations.