A joint theoretical/experimental study to predict Al/CuO nanolaminates thermal ageing

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Energetic materials are the only attractive sources of "dormant" energy, enjoying long shelf life (decades), that can deliver quick on-demand bursts of energy in the form of heat and/or pressure. Among the large variety of energetic materials, reactive nanocomposites, based on exothermic thermite reactions, have attracted great attention over the last two decades with the investigation of different types of reactive mixed nanopowders. A less common method is to sputter deposit alternating layers of Al fuel and oxide (mostly CuO) to form nanolaminate films. This category of reactive nanocomposites is very interesting for on-chip integration and have been applied in many applications such as in micro initiators, MEMS heat sources for welding or soldering or exploding foil initiators for several reasons. Although the integration of energetic materials with other microscale devices has been studied and demonstrated for more than a decade, the prediction of material ageing which is a key issue for a system supposed to stay in sleeping mode for decades, is inexistent.

This work proposes a dual approach to study the ageing mechanisms in Al/CuO nanolaminate films. The first approach consists of performing a series of DSC (Differential scanning calorimetry) runs with different heating rates and applying an isoconversional method that determines the values of the activation energy, E_α as a function of the reaction progress, without assuming any particular form of the reaction model. The obtained kinetic parameters are utilized to model the evolution of the material at various temperatures in isothermal conditions. We predict that under 250°C the reaction progresses very slowly on the time scale of months for Al/CuO and CuO/Al samples.

The second approach relies on a set of experimental characterizations, implying TEM (Transmission Electron Microscopy) and XRD (X-ray Diffraction) techniques at various reaction steps to understand the fundamental mechanisms involved during thermal ageing such as atomic diffusion, crystallization, and formation of new species (alloys). We demonstrate that as a function of different annealing temperatures (350°C, 500°C and 700°C), interface layer (Al/CuO, CuO/Al, Al/Cu/CuO and Al/ZnO/CuO) and time duration (200°C for 1 week), formation of binary and ternary alloys of Cu-Al-O-Zn is validated by XRD as well as a slightly decrease in the heat formation of the studied system.