Copper-μdiamond composites for nuclear fusion devices

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Copper alloys have been selected as first wall heat sinks due to their favorable thermal conductivity and radiation resistance [1]. However, the demand for operation temperatures above the range proposed for ITER first wall (<300°C) poses extra challenges, especially regarding thermal conductivity and mechanical strength [1]. The extremely high thermal conductivity of diamond turns its dispersions into excellent candidates for thermal management applications. Additionally, particle dispersions can be used as reinforcement for increased strength and, furthermore, Cu-Diamond composites with enhanced thermal conductivity will also exhibit lower thermal expansion [2,3] mismatch with plasma facing W- based materials than copper alloys.

Natural diamond is known to have the highest thermal conductivity (2000 W/(m.K), which compares with 390 W/(m.K) at 20°C for copper [4]). In the present work, natural micro diamond (μD) has been selected to reinforce copper in composites produced by mechanical alloying due to its strong resistance to amorphization and graphitization as compared, for example, with nanodiamond. Moreover, phonon scattering in diamond occurs for submicrometer crystallite size with a concomitant thermal conductivity attenuation. On the other hand, electrons dominate heat conduction in copper, whereas phonons control it in diamond. Hence, composite heat conduction requires energy transfer between electrons and phonons at the interfaces, which critically affects the material thermal behavior. Thermal conductivities as high as 50% above that of pure copper, have recently been achieved for Cu-Carbide-Diamond composites [5] and carbide interlayers are assumed to aid the necessary electron–phonon coupling although the interface role is not well understood [6].

The aim of the present study is to develop Cu/μD composites for heat-sinks integrated in first wall panels of nuclear fusion reactors. Powder mixtures of Cu and μD have been mechanically alloyed with Cr. The reinforcement dispersion was monitored for different milling times by X-ray diffraction and electron microscopy which were also used to study the chromium carbide at the interfaces. The load transfer ability of the interfaces was evaluated by microhardness measurements and through Young Modulus maps produced by nanoindentation. This information was used to infer the quality of the interfaces and its effect on the thermal properties of the material.

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