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WC-Cu thermal barriers for fusion applications

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ABSTRACT

WC-Cu cermets have been devised for thermal barriers between the plasma facing tungsten tiles and the copper-based heat sink in the first wall of nuclear fusion reactors. Composite materials with 50 and 75 v/v% WC have been prepared by hot pressing at 1333 and 1423 K with pressures of 37 and 47 MPa, respectively. Microstructural changes have been investigated by scanning electron microscopy coupled with energy dispersive X-ray spectroscopy and X-ray diffraction. The materials consolidated have also been evaluated in terms of Archimedes' density, thermal diffusivity, Vickers hardness and elastic modulus. Implantation was carried out at room temperature with Ar^+ at 100 keV ion beam with a fluence of $4 \cdot 10^{20}$ at/m^2. The materials consisted of homogeneous dispersions of WC particles in a Cu matrix and presented densifications of about 90%. Incipient swelling in copper-rich regions have been observed on the implanted surfaces, however no significant changes have been detected by X-ray diffraction. Higher WC content in the cermet materials increased hardness and the elastic modulus. The cermets' thermal diffusivity was significantly lower than that of pure copper or tungsten, as desirable for a thermal barrier.

1. Introduction

The high melting point, high sputtering threshold and low tritium inventory turn tungsten into a suitable material for plasma facing and structural components in the first wall of nuclear fusion reactors. However, a major disadvantage of current tungsten-grades is their relatively high ductile-to-brittle transition temperature [1]. Therefore, operation at high temperatures is desirable to preserve the integrity of W components and also meets the purpose of increasing reactor efficiency. A CuCrZr alloy has been selected as heat sink material to remove heat from the plasma facing components due to its high conductivity, strength and microstructural stability [2]. However, the service temperature of this material is relatively low and operation at higher temperatures demands thermal barriers between the plasma-facing W and the CuCrZr heat sink.

A WC-Cu cermet interlayer serving as thermal barrier for fusion applications is proposed in this work. Tungsten carbide (WC) combines favorable properties, such as lower thermal conductivity than pure tungsten [3] and similar thermal expansion behavior [4], with sufficient electrical conductivity [5] and high melting point [5]. In addition, WC shows good wettability by molten metals, like copper [5]. Both carbon and tungsten have very low solubility in liquid copper and the high hardness of WC [5] is expected to act as mechanical reinforcement of the composite material. Therefore, WC-Cu cermets are promising as thermal barrier interlayers between W tiles and the Cu-based heat sink, allowing for graded transitions. A previous study revealed that 25 vol% Cu can effectively reduce the large difference in thermal expansion between tungsten and the copper alloy [6] and the same can be expected for WC-Cu cermets with even lower thermal conductivity. High-energy neutrons resulting from fusion reactions induce atomic displacement cascades in first wall materials and the response of the proposed thermal barriers to irradiation requires elucidation.

The present work is focused on the characterization and testing of WC-Cu cermet materials sintered by hot pressing. The materials were implanted at room temperature with Ar^+ at 100 keV ion beam with a fluence of $4 \cdot 10^{20}$ at/m^2. Scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction

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