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Microstructure and mechanical properties of W/Cu vacuum diffusion bonding joints using amorphous Fe–W alloy as interlayer

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ABSTRACT

W/Cu Functionally Graded Materials (FGM) are promising materials to be used as plasma facing materials (PFM) for a fusion reactor as well as a heat sink material for high power microelectronic devices. The immiscible properties in W and Cu, however, make it difficult to join each other without introduction of active metals like iron group elements. In this paper, pulse electro-deposited Fe–W amorphous alloy forming on a copper sheet was proposed as interlayer to join W and Cu via vacuum diffusion bonding. It was found that an improvement in bonding strength and a decrease in bonding residual stresses was obtained by the bidirectional diffusion of Fe, in the form of highly active amorphous state, in W and Cu at the weld temperature. The diffusion transition regions were formed near the W/Cu interface which is consisted of a solid solution zone and various phases between the Fe–W and Fe–Cu binary systems and two different fracture phenomena was observed on the basis of the microstructural characteristics. With the introduction of this new kind amorphous coating as interlayer, the vacuum diffusion bonding joint of W and Cu heating at 950 °C for an hour with a load of 30 MPa showed a maximum tensile strength of about 146 MPa.

1. Introduction

The refractory metal tungsten is recommended as the leading candidate for the divertor section of the International Thermonuclear Experimental Reactor (ITER) because of many favorable properties such as high melting point, high sputtering threshold, high thermal conductivity and a low coefficient of thermal expansion [1–5], and copper has been proposed as the heat sink material behind the plasma facing materials (PFM) due to its high thermal conductivity, high electrical conductivity and high ductility [6,7]. However, the large difference in melting point and coefficient of thermal expansion between these two metals makes it very difficult to join them together.

Several methods have been developed to fabricate W/Cu Functionally Graded Materials (FGM), such as hot isostatic pressing (HIP) bonding [7], diffusion bonding [8], powder metallurgy [9–11], Vacuum plasma spraying [12], mechano-chemical progress [13], infiltration process [14], direct metal laser sintering [15,16], field-assisted sintering [17], etc. Braze welding is also an effective method to fabricate W/Cu FGM. The use of CuMn base brazing alloy demonstrated a good tensile strength of joint ~200 MPa with failure in the Cu alloy near the brazed joint, the high temperature brazing however is not compliant with ITER new specifications [18–20]. Plasma spraying is another promising method to fabricate W/Cu FGM. Tungsten has been successfully plasma sprayed onto oxygen-free copper in thicknesses up to 1 mm under inert gas protection [21]. The intrinsic limitation of this technique is the contamination of oxygen and carbon due to higher level of oxygen at 0.2% has been found in those coatings.

One of the most important methods for bulk material fabrication is powder metallurgy. However because the W–Cu system exhibits mutual insolubility or negligible solubility, W–Cu powder compacts show very poor sinterability, even by liquid phase sintering above the melting point of the Cu phase. Although every method has its own merits, the interface compatibility, however, is still the core issue challenging the existing processes.

Although the common welding defects such as cracking and distortion can be avoided through diffusion bonding technology [22,23], the application of conventional fusion welding to join the

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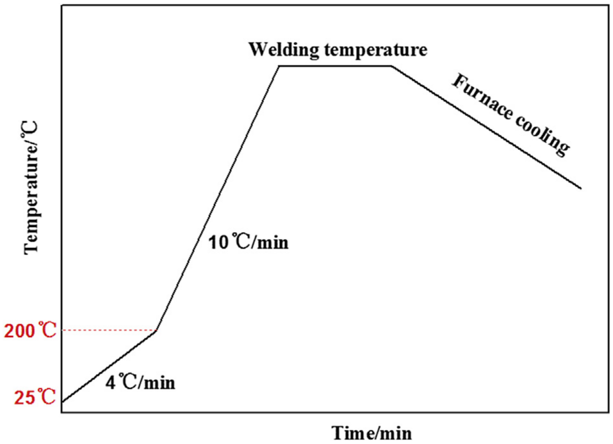

Fig. 1. Heating curve for tungsten and copper bonding.

dissimilar alloys is not feasible because of the large difference in the melting points between these alloys. In this study, the possibility of fabricating W/Cu FGM with a new kind of amorphous Fe–W coatings electrodeposited onto the Cu foils by vacuum diffusion bonding (VDB) is explored. A Cu foil with thickness of 30 μm was used as an interlayer and the effect of bonding temperatures on the microstructural developments across the joint and the resulting mechanical properties was investigated. In the previous works [24,25], the effect of the amorphous Fe–W coating transformation from non-crystal to crystal on W–Cu composite materials was studied in detail. During the bonding process, the Fe–W deposit undergoes a change from the amorphous to nano crystals of alloy compounds with grain sizes of 58.6 nm, 26.3 nm for W and Fe_2W, respectively. In the current research, the effect of bonding temperatures on the microstructure and mechanical properties of the joint interfaces were studied extensively.

2. Experimental details

2.1. Electrodeposition of amorphous Fe–W coatings on Cu

Fe–W amorphous alloys were electroplated using an aqueous solution containing 0.212–0.243 mol L^{-1} ferrous sulfate heptahydrate, 0.018–0.036 mol L^{-1} sodium tungstate dehydrate and 0.26 M ammonium tartrate. Tartaric acid complex system was selected as the complex agent in the study. A pH value of 8.0 was maintained by adding either ammonia or dilute sulfuric acid. For every electroplating, the current density was set to be 0.05 A cm^{-2} and the plating temperature as 60 °C, while the time was fixed to 8 min. Amorphous Fe–W coatings were prepared by electroplating onto the surface of Cu foils. Cu foil is chosen as the substrate because of its high thermal conductivity and excellent plasticity. Before deposition, the Cu foil sample was electrochemically polished with phosphoric acid, washed by distilled

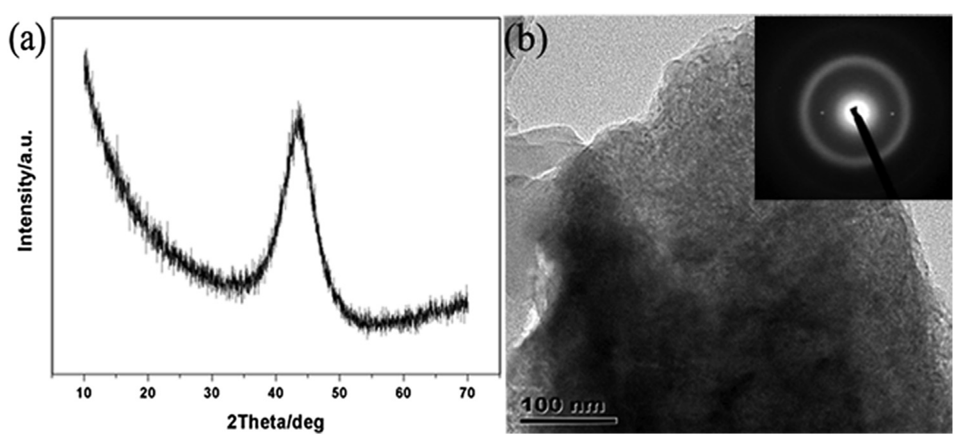

Fig. 2. (a) XRD pattern for Fe–W coating; (b) TEM selected area diffraction pattern for Fe–W coating.

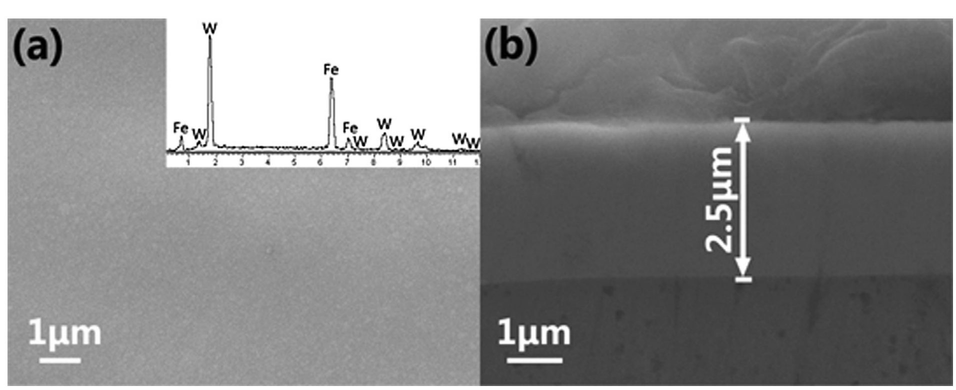

Fig. 3. (a) SEM top view morphology of as-deposited Fe–W coating; (b) Cross-section morphology.