Interface characterization of a W coated diamond/Al composite for thermal management applications

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1. INTRODUCTION

Over the last decade, a diamond particle reinforced Al matrix, namely diamond/Al, composite has been developed for thermal management applications, mainly in the microelectronic industry. This composite has demonstrated an excellent combination of a Thermal Conductivity (TC) as high as 600 W/mK and a Coefficient of Thermal Expansion (CTE) lower than 10 ppm/K, being compatible with that of electronic components. However, considering the TC (~ 1800 W/mK) of the diamond particles incorporated, it is clear that the overall TC enhancement has not been completely exploited in the composite. One then points at the diamond/Al interface, which should provide good adhesion as well as maximal Interfacial Thermal Conductance (ITC) in order to facilitate thermal exchange across the interface.

Our analytical modelling has recently predicted that introduction of a W interface nanolayer is one of the most efficient ways to achieve high ITC, which provides a practical guide for interface engineering [1]. Accordingly, a cost-effective sol-gel process has been tentatively used to deposit a W coating for diamond surface metallization. Compared with the diamond/Al counterpart without a W nanolayer, TC of the composite with a W nanolayer improved more than 20 % [2]. In this work, Scanning Transmission Electron Microscopy (STEM)/Energy-Dispersive X-ray spectroscopy (EDX) and Precession Electron Diffraction (PED) have been performed in order to investigate interface configurations of a W-coated diamond/Al composite. The aim is to study the effect of interface formation, reaction and diffusion on the ITC.

2. RESULTS

2.1 Experimental conditions

The W nanolayer was deposited on the surface of diamond particles by a sol-gel approach; W coated diamond/Al composites were produced by an optimized Vacuum Hot Pressing (VHP) process [2,3]. Scanning probe microscopy (SPM) was conducted using a SII Nanonavi E-Sweep Environment Control instrument to observe topography of the W coated diamond particles. An almost flat surface of the composite was acquired by triple ion beam cutting [4], which was followed by focus ion beam preparation to have site-specific TEM samples ready for interface characterization. A state-of-the-art FEI "X-Ant-EM" microscope, equipped with a probe aberration corrector and a highly efficient (4 quadrant) EDX system and operated at 120 kV, was used for STEM/EDX characterization. PED was performed by using a Philips CM20 microscope equipped with a Nanomegas 'Spinning Star' precession unit using a precession semi-angle of 2°.

2.2 Results

The deposited W coating is discontinuous, and consists of nanoparticles with a size in the range 30-400 nm and homogenously covering the surface of the diamond particle (Figs. 1a and 1b). The average coating thickness is estimated to be around 200 nm (Fig. 1c). A STEM/ADF image in Fig. 1d shows that the formed diamond/Al interface has a heterogeneous configuration at the nanoscale where Al grain contrasts and a particle with high Z contrast are revealed. STEM/EDX mapping in Fig. 2 displays a W and Al rich interfacial particle. Visible O traces can be related to fine microstructural features. Alternatively, a 'clean' diamond/Al interface is tightly-adhered and is not rich in O (Fig. 3). As shown in Fig. 4, PED zone-axis patterns recorded from the W and Al rich particles are indexed to be the $Al_{12}W$ phase (Cubic, *I2/m-3*, No. 204). Such different chemical nature of the bonds at the interface can have a pronounced effect on the local ITC.

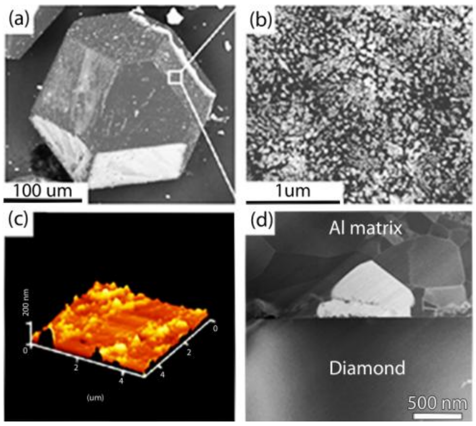

Figure 1. SEM images showing the morphologies of (a) a W-coated diamond particle, (b) deposited nanoparticles, (c) deposition thickness measured by SPM and (d) STEM/ADF image of a diamond/Al interfacial area

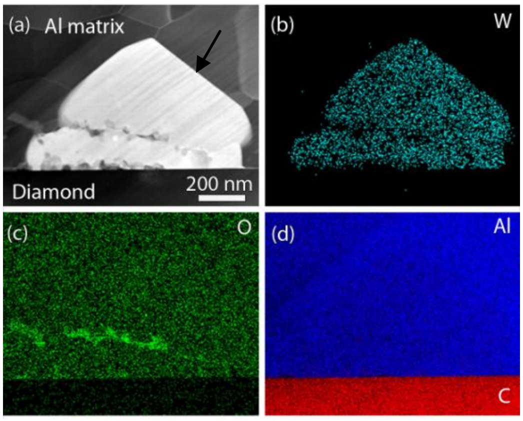

Figure 2. STEM/EDX analysis of the diamond/Al interfacial area containing a deposited particle: (a) ADF image, (b) corresponding W, (c) O and (d) mixed Al and C elemental mappings

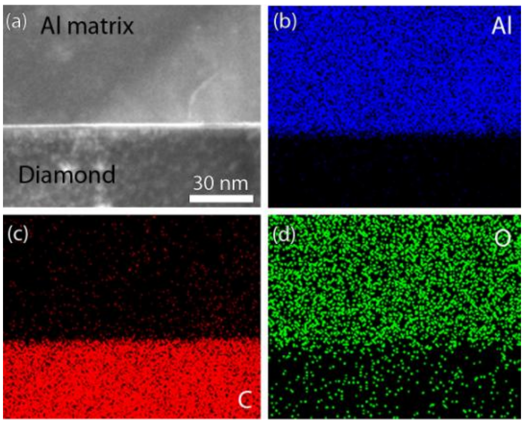

Figure 3. STEM/EDX analysis of the 'clean' diamond/Al interface: (a) ADF image, (b) corresponding Al, (c) C and (d) O elemental mappings

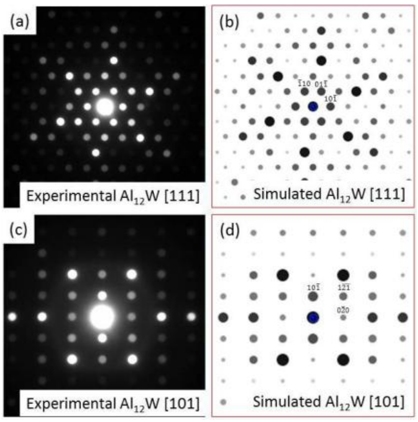

Figure 4. PED analysis of the deposited particle arrowed in Fig. 2a: (a) and (c) experimental zone-axis patterns, (b) and (d) corresponding simulated patterns of the $Al_{12}W$ phase

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