

Role of Solid-State Skeletal Sintering during Processing of Mo-Cu Composites

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Mo-Cu composites with Mo contents up to 85 wt pct can be processed by either infiltration of a presintered Mo skeleton with liquid Cu or by liquid-phase sintering of mixed Mo and Cu powders. For both cases, the effects of particle size, sintering temperature, and sintering time on densification and microstructural evolution are compared. The effects of transition metal additions on the densification of Mo-Cu are also investigated. The liquid-phase sintering densification rate of Mo-Cu is much slower than in traditional liquid-phase sintering and is similar to the solid-state densification rate of elemental Mo. Furthermore, the poor densification behavior and absence of slumping for compositions up to 50 vol pct Cu indicate that the high dihedral angle of the Mo-Cu system stabilizes the formation of a rigid Mo skeleton during liquid-phase sintering. Results from a computer simulation that takes into account mass transport *via* both solid-state and liquid-phase mechanisms show that the solubility of Mo in Cu is sufficient for rapid densification, but confirm that the sintering behavior of Mo-20 vol pct Cu is best described by solid-state skeletal sintering. In this case, the liquid phase promotes microstructural coarsening by solution reprecipitation but contributes little to densification because of the rigid Mo skeleton.

I. INTRODUCTION

MO-CU composites combine the refractory properties of Mo with the high conductivity of Cu and can be tailored to specific applications by adjusting the relative amounts of these constituents. Traditional applications, such as electrical contacts, typically require relatively high Cu volume fractions and also have a low degree of shape complexity; consequently, they can be produced by sheet rolling or by die pressing elemental Mo and infiltrating it with Cu.^[1-4] Newer applications for Mo-Cu include microelectronic packaging, where a thermal expansion match to silicon is desired along with a high thermal conductivity.^[5-13] For these applications, Mo volume fractions of 80 to 85 wt pct are desired. Both infiltration and liquid-phase sintering are potential processing routes for these compositions.

Achieving high infiltrated densities for Mo-Cu composites containing 80 to 85 wt pct Cu requires high green densities or densification during sintering of the elemental Mo skeleton. The latter case is mandated for some microelectronic packaging applications in which the shape complexity requirements can only be met by powder injection molding, since the green density in this process is limited by the critical solids loading of the powder. Prior studies of the sintering of elemental Mo identified volume diffusion as the dominant densification mechanism;^[14-17] however, concurrent grain growth slows densification.^[18] Densification of Mo is greatly enhanced by the addition of transition metals, especially Ni and Pd,^[16-19] and by reducing the grain boundary mobility to inhibit grain growth.^[20] However, transition

element additions are detrimental to the thermal conductivity,^[2,6,10] so their use is discouraged for electronic packaging applications.

Liquid-phase sintering of mixed Mo and Cu powders is an attractive processing route for the compositions of interest in microelectronic packaging, but densification is hindered by the low solubility of Mo in Cu. Liquid-phase sintering of Mo-Cu requires small starting powders, and powder preparation techniques have a large effect on the densification behavior and final microstructure due to the lack of homogenization during sintering.^[9,21] These characteristics differ from those of traditional liquid-phase-sintered systems, such as W-Ni-Fe, which have high solubility of the solid in the liquid.

Although limited work has been published on liquid-phase sintering of Mo-Cu, more extensive studies have been conducted with the W-Cu system,^[6,7,10-13,22-33] which is chemically similar to the Mo-Cu system. For W-Cu, a previous model^[34] determined that high sintered densities can be achieved *via* solid-state sintering of submicrometer W powders in the presence of liquid Cu, even though the liquid Cu contributes little to densification. The current study compares the densification behavior of elemental Mo and liquid-phase-sintered Mo-Cu to determine the role of solid-state skeletal sintering for both cases. The effects of particle size, sintering time, sintering temperature, transition element addition, and volume fraction of liquid phase on densification, microstructural evolution, and shape retention are examined. The experimental densification results are compared to a quantitative model for solid-state and liquid-phase sintering.

II. EXPERIMENTAL PROCEDURES

Two Mo powders were supplied by Climax Specialty Metals (Cleveland, OH) and two Cu powders were supplied by ACuPowder (Union, NJ). The 2000 grade Cu powder

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