Evolution of the Nanoporous Microstructure of Sintered Ag at High Temperature Using *in-Situ* X-ray Nanotomography

Next generation power electronics modules are designed for higher power dissipation and a higher reverse breakdown voltage in order to optimize their electric efficiency. In this context, Si chips must be replaced by wide-band gap semiconductors such as SiC which are able to sustain much higher operating temperatures. As a result, there is a need to re-evaluate the materials used in power modules. Silver (Ag) paste sintering is regarded as one of the potential bonding technologies for the future power modules, since Ag exhibits a high melting temperature as well as better electrical and thermal properties compared to those of the classic solder alloys. However, the elaboration conditions (low pressure, low temperature) result in a porous Ag joints likely to compromise the properties compared to those of bulk Ag and even alter the lifespan of the entire system. In this context, developing a fundamental insight on the evolution of the connectivity, pore geometry and pore spatial distribution as well as the overall density with aging could provide a rational basis for developing predictive models on the entire system behavior. Previous studies were successful in qualitative evaluation of the properties of the porous sintered Ag. However, quantitative porous structure analysis is rare, either in 2D and 3D specifically when aging in temperature is involved.

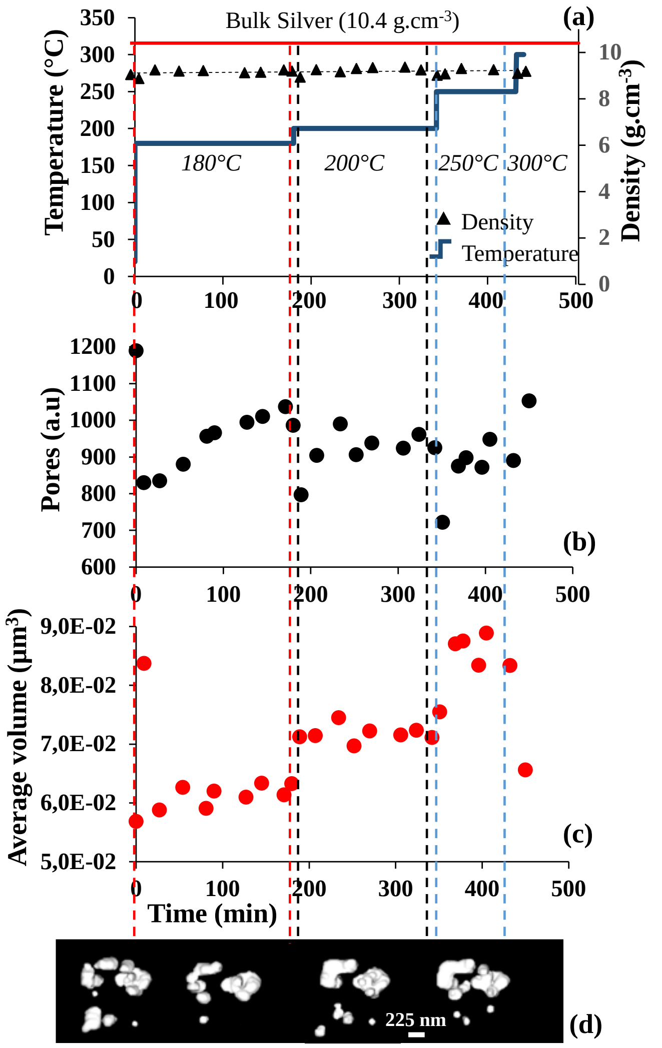

Figure 1. Evolution with temperature / time : a) thermal loading (solid blue curve) and density (black triangular symbols) vs time. The horizontal solid line represents the theoretical Ag density (10.4 g/cm^3) b) number of pores versus temperature/time, c) average pore volume versus temperature/time, d) details of nanopore evolution in 3D.

A research team led by Dr. Xavier Milhet (Institut Pprime – France), Dr. Marc Legros (CEMES – France), Dr. Yijin Liu, and Dr. Doug Van Campen (SSRL) studied the evolution of the nanoporous structure *in-situ* during thermal aging using transmission x-ray microscopy (TXM) at the nanotomography Beam Line 6-2c fitted with a specifically designed heater providing temperatures between 180°C and 300°C. Controlled temperature jumps at 1°C/s followed by hold time at the target temperature were performed to give an insight into the dynamic evolution of the nanopores under potential operating conditions.

The direct monitoring of the nanoporous structure at line BL6-2c allowed, for the first time, the quantitative analysis of its evolution during thermal excursions (Figure 1). The first striking result was that the average porosity remains constant in the temperature range 180°C – 300°C, i.e. when aging occurred at a temperature different from that of the sintering (240°C) (Figure 1a). Aside from the continuous growth of the larger pore, two regimes are observed: i) just after a temperature jump, for which the material is away from its thermodynamical equilibrium, the number of pores decreases while the average pore volume increases; and ii) at the end of the hold time at the target temperature (either 180°C, 200°C or 250°C) for which the material evolves towards its thermodynamic equilibrium at a given temperature - the number of pore increases and the average pore volume decreases (Figures 1b and 1c). This is accompanied by a motion of the centers of gravity of the pores towards the center of the pillar just after a temperature jump, while the reverse motion occurs during the hold time at constant temperature. This was shown to result from a competition between pore coalescence / ripening trying to minimize the surface energy on the one hand and the pore shrinkage just after the temperature jump on the other hand (Figure 1d).

These studies highlight the need for more detailed study of (i) the interaction between pores and the interface with a substrate (dewetting, chemical reactions…); (ii) the role of the gaseous atmosphere on the evolution kinetics; and (iii) *in-situ* thermal fatigue tests. Future *in-situ* aging studies using the *in-situ* heater, 3D TXM at the nanometer scale, as well as spectroscopy at Beam Line 6-2c will seek to provide insights into these topics, thereby advancing the fundamental understanding of nanoporous material aging.

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