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学位の種類	博士（工学）・甲（課程博士）第 1 号	
博士論文題目	Mechanical Reliability of Sintered Nano Silver for Power Device Packaging	
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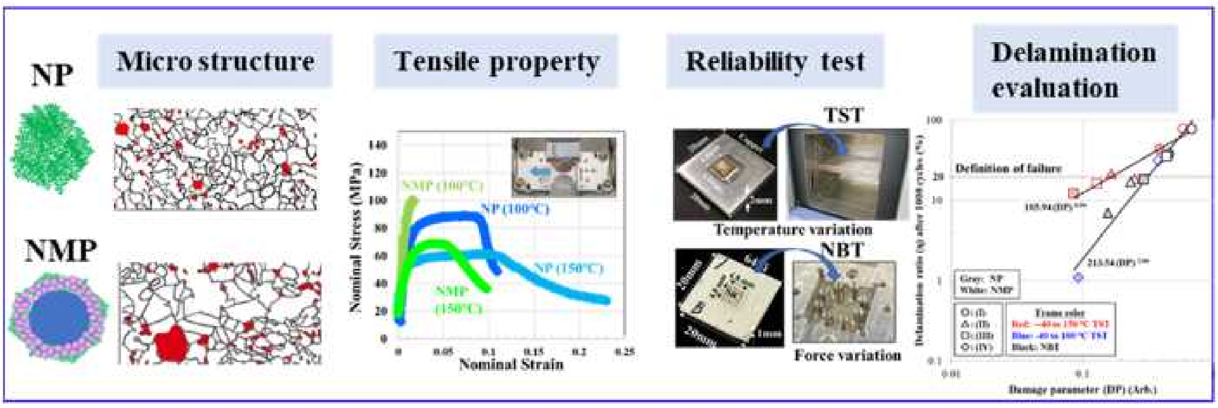
論文の概要

A new die bonding technique that can provide good stability despite severe thermal density is necessary to maximize the performance of WBG devices. Considering its high heat conductivity of over 200 W(m/K) and a high melting point of 961℃, a sintered silver (s-Ag) material has been considered as a strong die-attach material candidate for WBG devices. However, for the practical use of products, the s- Ag die layer is commonly assessed with a thermal shocked test (TST) that evaluates material degradation by heating and cooling. During TST, thermal and mechanical stresses are generated in the die layer because materials with different coefficients of thermal expansion can cause thermal warpage around a bonded part. Consequently, the die layer fractures. In achieving long-term mechanical and thermal durability, the failure mechanism should be clarified experimentally.

This study aims to establish a packaging reliability design flow with s-Ag die assembles based on the mechanical reliability evaluation of the s-Ag material. As shown in the figure with a blue frame, this research covers s-Ag microstructure analysis, film mechanical property evaluation, bonding reliability evaluation of mechanical bending test, thermal cycling test, and degradation evaluation using an original damage parameter (DP).

Two types of s-Ag paste (NP, nanosized paste; NMP, nano-to-micro-sized paste) were used. The sintering condition was set to 300℃ for 10 min with pressure of 60 MPa. After sintering, each mean porosity (pr) of NP and NMP was 5% and 8%, respectively. In addition, the grain size of NP was about half of the grain size of NMP. In addition, NP has large ductility, showing plastic deformation above 100℃, whereas NMP has little ductility. That is, a finer microstructure provides better durability of s-Ag. With regard to the mechanical bending test, a new bending test technique, namely, nine-point bending test (NBT), has been proposed, which provides out-of-plane deformation with s-Ag die-attached assembles (DAAs) such as TST. In comparing NBT with TST, an experimental condition of each test was determined on the basis of the finite element analysis calculation results with averaged accumulated von Mises plastic strain (APS) at the s-Ag die layer as a general engineering parameter. A similar degradation ratio between NBT and TST was obtained in scanning acoustic tomography (SAT), which indicates that mechanical stress plays a significant role in deteriorating the s-Ag die layer during TST. However, TST with a high APS region shows large dispersion of delamination ratio compared with NBT with the same region. Cross- sectional microanalysis indicates that s-Ag material aging and mechanical cracking coexisted in the case of large APS condition with TST. Finally, the DP is defined as the ratio of APS value to plastic strain value obtained from tensile test results. The delamination ratio after 1000 cycles of TST and NBT could be separately fitted by two linear approximation lines with "Aging case" and "non-Aging case" in a double logarithmic graph. Molecular dynamics (MD) simulation and classical pore growth discussion indicate that a pore can grow under only a tensile stress state at a high temperature, which would lead to the difference between the two degradation mechanisms.



論文審査結果要旨

The doctoral thesis aims to establish a reliable packaging design with sintered silver (s-Ag) die attach assembles by means of s-Ag microstructure analysis, s-Ag film mechanical characterization, and s-Ag die attach reliability evaluation. This applicant proposes a damage parameter (DP) as a new index for evaluating the degradation of s-Ag die attach assembles dominated by multiple degradation mechanisms. The doctoral thesis can be evaluated in the following points:

Firstly, the applicant experimentally revealed that the brittle-ductile transition temperature of the s-Ag films made of the two types of s-Ag pastes (NP: nano paste and NMP: nano-micro paste) was dependent on porosity, pore size, and pore shape. Then, the applicant found that s-Ag die attach assembles was dominated by multiple degradation mechanisms, mechanical degradation based straight cracking and thermal aging based wavy cracking, by comparing thermal shock test (TST) results and nine-point bending test (NBT) results. As a new index of the packaging reliability design, the applicant proposed a DP given by mean plastic von Mises strain (plastic flowability) over plastic strain range (plastic resistance). It worked well to fit the two damages originating from mechanical cracking and aging separately. The DP can be considered as one of the appropriate evaluation parameters for s-Ag die attach degradations, and its value can be highly evaluated. Moreover, the applicant found that high temperature and tensile stress applied were required to grow pores inside the s-Ag die layer. By using a classical pore growth theory, the applicant successfully made the critical stress plane for pore growth as a new degradation criterion and concluded that the wavy cracking originated from pore growth during TST. Lastly, through the knowledge obtained, the applicant proposed a new power module production flow using sintering die attach process with other nanoparticles for reducing process time and cost in future power module packaging.

Towards a reliable packaging design with s-Ag die attach assembles, the doctoral thesis established a promising production flow including simultaneous evaluation of multiple degradations using the PD proposed. This would be of great worth both scientifically and industrially. Therefore, the thesis review committee has made a decision that the doctoral thesis has been accepted.

口頭試問結果要旨

At the defense, the applicant was evaluated from scientific, theoretical, technical, and industrial aspects. The examiners confirmed that the applicant had appropriate knowledges, skills, and experiences in this field. The applicant's achievements include in total six peer reviewed journal papers, one invited review paper, nine international conference presentations, eight domestic conference presentations, one book chapter, and two awards, which were highly evaluated.

Based on all the above points, the thesis examination committee made a decision that Keisuke Wakamoto deserves to receive a Doctor of Engineering from KUAS.