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Degradation Behaviors of Adhesion Strength between Epoxy Resin and Copper under Aging at High Temperature

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Abstract

The aim of this study is to investigate degradation behaviors of the adhesion strength of the resin (bisphenol F-type epoxy resin)/metal interface under aging at high temperature. The adhesion strength of the Cu joint with the resin was investigated by the tensile test. Fracture surfaces were analyzed by Fourier transform infrared spectroscopy (FT-IR) to investigate the degradation mechanism of the adhesion strength of the resin/Cu interface. The tensile strength of the resin itself was also investigated. Although the tensile strength of the resin was 83.3 MPa before aging, it fell to approximately half after aging at 175 ^{o}C for 100 h and gradually decreased with aging until 1000 h. The degradation of the resin was caused by thermal decomposition and oxidation of it. The tensile strength of the Cu joint with the resin is 8.9 MPa before aging and it gradually decreased with aging at 175 ^{o}C and fell to half or less after aging for 1000 h. The strength of the Cu joint with the resin was lower than the tensile strength of the resin. The degradation of the adhesion strength was caused by cutting C-C bonds by thermal decomposition of the resin. The cut C-C bonds reacted with H_2O in the interface and thus the number of hydrogen bonding between hydroxy group and the Cu oxide film decreased. The reduction of hydrogen bonding caused to decrease the strength of the resin/Cu interface.

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Keywords: Power module; Epoxy resin; Copper; Adhesion strength; Fracture surface

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1. Introduction

To reduce discharge carbon dioxide from automobiles and industrial equipment, electricity has been utilized as alternative energy of the oil. The electronic control of many kinds of machines has advanced and power modules which can control large-capacity electricity have spread. In recent years, next generation power modules with SiC and GaN power semiconductors have been studied. In such power modules, polymer has been widely used for packaging materials to protect power modules from external shocks under severe environment [1, 2]. Since there are many resin/metal interfaces in the modules, high reliable resin/metal interfaces under thermal cycle, power cycle and high temperature conditions are required to achieve high performance and high reliability of the modules [3, 4]. The aim of this study is to investigate degradation behaviors of the adhesion strength of the resin (bisphenol F-type epoxy resin [5])/Cu interface under aging at high temperature. The adhesion strength of the resin/Cu interface was examined by the tensile test. The fracture mode was examined by fracture surface observation and the degradation mechanism of the adhesion strength of the resin/Cu interface was investigated. The tensile strength of the resin itself was also investigated.

2. Experimental procedure

Bisphenol F diglycidyl ether and bis (4-amino-3-ethylphenyl) methane were prepared as a matrix resin and a curing agent, respectively. The matrix resin and the curing agent were kneaded in the ratio of 10 : 4 (mass% ratio). After kneading, degassing treatment was conducted under decompression of 70 Pa for 2 h at R.T. To investigate the tensile strength of the resin itself, a dumbbell specimen shown in Fig. 1 was prepared. Fig. 1 shows shape and dimensions of the specimen and its general view. The specimen was fabricated with a Teflon mold. The degassed epoxy resin applied into the mold was set on the hot plate of 80 ^{o}C and subsequently was cured at 150 ^{o}C for 4 h using an oven in the atmosphere. After curing, the surface of the specimen was polished with a #500 abrasive paper. The aging treatment was conducted at 175 ^{o}C for 1000 h using the oven in the atmosphere. The tensile test was conducted at a crosshead speed of 0.1 mm/s. Three specimens were tested under each condition. The surfaces of the gage areas were analyzed by Fourier transform infrared spectroscopy (FT-IR). The FT-IR analysis was conducted by the attenuated total reflection (ATR) method using an infrared microscope.

To investigate the tensile strength of the Cu joint with the resin, Cu rivets were bonded with the epoxy resin. The shaft diameter, the head diameter and the height of the Cu rivet were 2.0 mm, 4.0 mm and 3.0 mm, respectively. The adhesive surface of the Cu rivet was polished with a #1000 abrasive paper and subsequently oxidation treatment for the surfaces was conducted at 150 ^{o}C for 60 min and 60 ^{o}C for 60 min using the oven in the atmosphere. The gap between two rivets was set to 0.1 mm using a bonding tester (RHESCA STR-1000) which stage temperature was 150 ^{o}C and the degassed epoxy resin was applied in the gap and cured at 150 ^{o}C for 2 h for pre-curing. After pre-curing, additional cure was conducted at 150 ^{o}C for 2 h using the oven in the atmosphere. The aging treatment was conducted at 175 ^{o}C for 1000 h using the oven in the atmosphere to investigate the effect of the aging on the tensile strength of the joint. The tensile test was conducted at a tensile rate of 0.1 mm/s with the bonding tester. Three specimens were tested under each condition. In this study, fracture mainly occurred in the resin/Cu interface regardless of aging time. Fracture surfaces on Cu sides were observed using a charge coupled device (CCD) microscope and the resin on fracture surfaces were analyzed by FT-IR. The FT-IR analysis was conducted in the same way as described above.

3. Results and discussion

3.1. Tensile strength of resin material

Fig. 2 shows the change in tensile properties of the resin material with aging at 175 ^{o}C. Although the tensile strength of the resin was 83.3 MPa before aging, it fell to approximately half even after aging at 175 ^{o}C for 100 h. Afterwards,