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# Diffusion Soldering of Pb-Doped GeTe Thermoelectric Modules with Cu Electrodes Using a Thin-Film Sn Interlayer

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Directly coating a GeTe(Pb) thermoelectric device with a Ni barrier layer and an Ag reaction layer and then diffusion soldering with a Cu electrode coated with Ag and Sn leads to breakage at the GeTe(Pb)/Ni interface and low bonding strengths of about 6 MPa. An improved process, precoating with 1 $\mu$m Sn film and heating at 250°C for 3 min before electroplating with Ni and Ag layers, results in satisfactory bonding strengths ranging from 12.6 MPa to 19.1 MPa. The precoated Sn film leads to the formation of a $(Ni,Ge)_3Sn_4$ layer between the GeTe(Pb) thermoelectric material and Ni barrier layer, reducing the thermal stress at the GeTe(Pb)/Ni interface.

**Key words:** Diffusion soldering, GeTe(Pb) thermoelectric modules, intermetallic compounds, bonding strength

## INTRODUCTION

Thermoelectric (TE) materials using the Seebeck effect or the Peltier effect are being developed in response to the energy crisis. The thermoelectric effect, which involves the transfer of heat and electricity, can be applied in power generators, heat dissipators, thermoelectric coolers, and waste heat recovery. However, the thermoelectric conversion efficiency of a single thermoelectric device is limited, so in general, TE modules are produced through a combination of multiple TE devices bonded with metallic electrodes for commercial applications. Traditionally, soldering or brazing methods are employed for the bonding of thermoelectric materials with electrodes. Although soldering at lower temperature can reduce thermal stress, the bonding interface may melt during subsequent operation of thermoelectric modules at high temperature. Brazing, on the other hand, allows operation at high temperature because the filler has a higher melting point. Unfortunately, while the bonded thermoelectric modules are cooling from the high temperature of the brazing process, high thermal stress may occur at the bonding interface. Such stress can damage thermoelectric devices. Consequently, since soldering and brazing methods both entail the risk of failure in the manufacture or operation of thermoelectric modules, an improved method should be developed. In the alternative method, the thermoelectric modules should be bonded at a temperature as low as possible, and the melting point of the joints should be higher than the working temperature of thermoelectric devices.

A novel bonding technique, called diffusion soldering, uses the principle of thin-film solid–liquid interdiffusion. This technique might solve the above problems. It employs a low-melting-point metallic thin-film interlayer (LT) that melts at low temperature and reacts rapidly with the sandwiched high-melting-point (HT-1 and HT-2) layers or with the substrates to form intermetallic compounds. The LT layer must be thinner than the HT-1 and HT-2 layers or substrates, and the reactions of the LT layer have to be exhausted entirely. This novel technique is suitable for application in emergent high-temperature electronic devices, which demand a low bonding temperature. It has been applied to the manufacturing of microwave packages,[1] high-power devices,[2] thick-film resistors,[3] GaAs/Si wafer packages,[4] ceramic multichip modules,[5] and even gold jewelry[6] in past decades. Recently, diffusion

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