Thick Copper and Aluminum Wire Bonding Technology for High Power Laser Devices

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Abstract

The trends of increasing demand of higher power laser devices with increased current capacity and total package cost reduction to improve dollars per watt of laser output power have resulted in the need for alternatives to traditional gold wirebonds on gold-plated substrates. Copper and aluminum wires are considered to be the leading candidates due to their vast reliability database in the semiconductor industry and cost advantages. Room temperature (25°C) wirebonding with a robust process window and high yield is required for high-volume, low-cost applications. The wirebonds must also meet or exceed the stringent reliability requirements of 1000 hours at 85°C/85%RH damp heat (DH) and 1000 hrs at 175°C high temperature storage (HTS) testing. In this study, 10 mils round thick copper and aluminum wire bonding has been successfully developed at room temperature with no intermetallic failure or void formation at the Al/Au and Cu/Au interfaces after 1000 hours of DH and HTS testing. Further investigation with corrosion-resistant Al wire shows excellent pull strength and wire shear per Mil-Std 883 after 2000 hours of DH and HTS testing with no evidence of void formation at the Al/Au interface. The thickness of the Au-Al intermetallic is found to be minimal at ~4um after 1000 hours of HTS testing. This study has demonstrated that both thick copper and aluminum wire are capable of wire bonding at room temperature to function as a reliable interconnect with improved product performance and low cost.

Key words

Thick Wire Interconnect, Aluminum and Copper Wire Bonding, Laser semiconductor.

I. Introduction

The continuous increasing power requirement of high power laser requires either an increase in the wire diameter or in the number of wires from the device to package interconnect. Consequently, low-cost alternatives to gold are being intensively developed. Typical alternatives available for integrated circuit (IC) devices are copper or aluminum wire. Both options have vast quality and reliability databases widely available for IC packaging. The transitional bonding pad top metallization for IC semiconductors is aluminum for either gold or copper wire bonding processes [1]. However, typically a gold pad is required for high power IC devices if the junction temperature is beyond 150°C during operation [2] due to the widely recognized reliability issues of that Au/Al intermetallic for high power devices that operated at elevated temperature [3,4]. Copper wire bonding on aluminum pad has improved reliability performance compared to a Au/Al intermetallic system due to slower Cu/Al intermetallic growth during aging [5]. Cu/Al has also demonstrated better reliability at the interface performance compare to Cu/Au with no Kirkendall voids observed after thermal aging [6].

For semiconductor lasers, the bond pad top metallization on the laser diode is typically sputtered with gold and die bonded on a gold-plated Aluminum Nitride (AlN) submount. The interconnect to the external contact is then performed with gold wire from the diode and the submount. For high power semiconductor lasers, multiple diode-on-submount assemblies are connected in series to achieve the intended power level. In this study, aluminum and copper wires are evaluated to replace the gold wire interconnect between submount to submount for cost reduction. Copper wire bonding on gold is a highly reliable interconnect due to the slower growth rate of the Cu/Au intermetallic system. Intermetallic diffusion rate of Cu/Au system is slower than Al/Au system [7,8] as shown by the similar diffusion constant but at higher activation energy and at higher temperature in Table 1. However, most of the reliability database for the Al/Au intermetallic system assumes gold wire bonding on aluminum pad and limited reliability information is available in the industry for aluminum wire bonding on gold pad.

Table 1 Diffusion rate comparison between Cu/Au and Al/Au system

System	Diffusion constant (cm^2/s)	Activation energy (kcal/mol)	Temperature range (^oC)
Al-Au	0.131	27.79	368-655
Cu-Au	0.15	45.6	400-1050

Optical components attached to the package prior to wire bonding process has also limited the bonding temperature to approximately 100^{o}C. In this study, the focus is to evaluate room temperature wire bonding for both aluminum and copper wires. Figure 1 (a) and 1 (b) show both 10 mils aluminum and copper wire successfully bonded on a gold plated submount at room temperature. Impurity-doped aluminum alloy wire has also demonstrated the ability to improve corrosion resistance under temperature and humidity aging [9,10].

Figure 1(a) 10 mils aluminum wires bonded on gold plated submount at room temperature

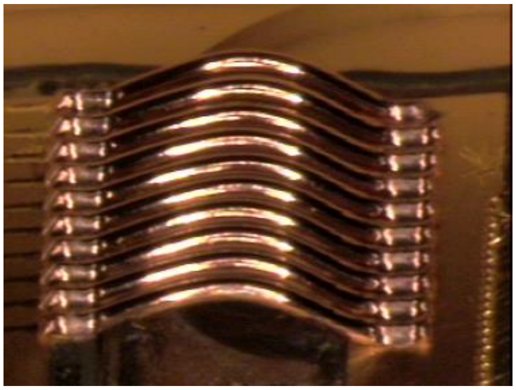

Figure 1(b) 10 mils copper wires bonded on gold plated submount at room temperature

II. Experiment and Result

A. Heavy Copper Wire Bonding

Heavy copper wire bonding at room temperature requires high bond force and optimized parameters in ultrasonic energy and bond time. For this study, a bond force greater than 1kg is used, which damaged bond pad on the edge of AlN submount (Figure 2). This damage can be avoided if the bond location is shifted further away from the submount edge, but this will increase the wire length and contribute to higher electrical resistance and lower wall plug efficiency of the laser module.

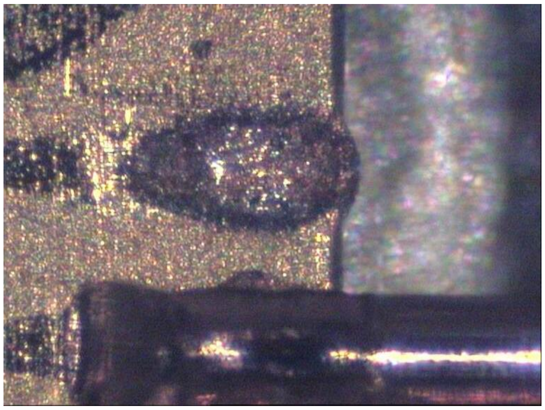

Figure 2 Bond pad deformation due to high bond force during wire bonding

The gold thickness on the submount is approximately 1µm thick. Figure 3(a) show that the Cu/Au intermetallic thickness increases to approximately 1-2 µm after 85^{o}C 1000 hours of high temperature storage testing. After 175^{o}C, 1000 hours the Cu/Au intermetallic is approximately 2-3 µm thick. The variation of the Cu/Au intermetallic thickness is largely due to the high bond wirebonding force, which compresses the intermetallic around and results in non-uniform thicknesses at the interface. No Kirkendall voids found in the Cu/Au intermetallic layer, which is consistent with the literature.

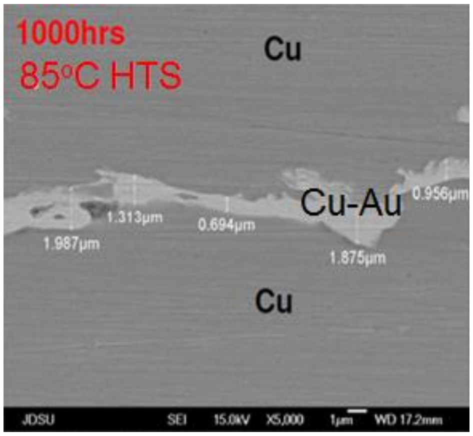

Figure 3(a) Intermetallic check of Cu-Au after 1000hrs of 85°C High Temperature Storage

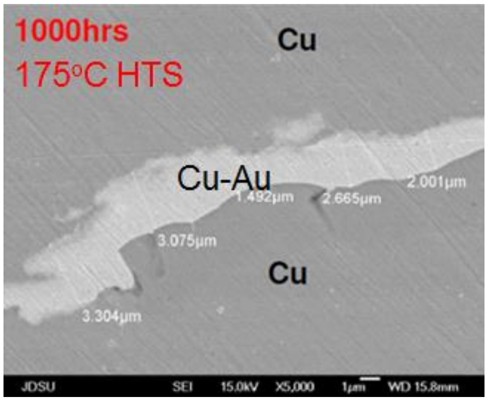

Figure 3(a) Intermetallic check of Cu-Au after 1000hrs of 175°C High Temperature Storage

B. *Thick Aluminum Wire Bonding*

Figure 4(a) shows a stable intermetallic Au/Al thickness after 1000 hours of high temperature storage testing at 85°C. The bonding force for the aluminum wire is approximately 300 grams, typical for 10 mils heavy aluminum wire. The Au_2Al intermetallic compound is dominant for 85°C aging. However, at 175°C high storage testing, the $AuAl_2$ predominates at the surface of the bulk aluminum. The $AuAl_2$ (or purple plague) is a well-known reliability concern to the Au/Al system due to its high porosity and resistivity among all other Au/Al intermetallic compounds. No sign of Kirkendall voids is found after 1000 hours of thermal aging at 175°C.

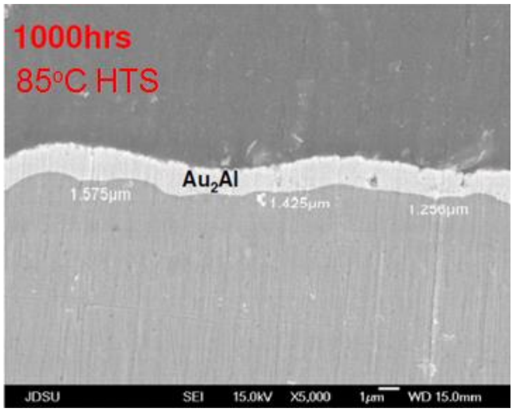

Figure 4(a) Intermetallic check of Al-Au after 1000hrs of 85°C High Temperature Storage

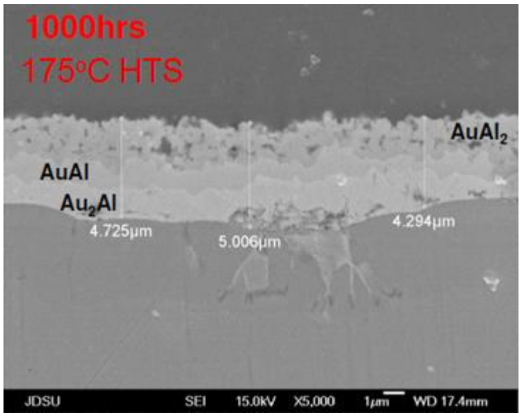

Figure 4(a) Intermetallic check of Al-Au after 1000hrs of 175°C High Temperature Storage

Severe corrosion after 1000 hours of 85°C/85% RH damp heat testing is shown in Figure 5. Pull test data reveals that approximately 30% pull strength reduction is observed compared to time-zero. Corrosion could be one of the key contributors to this pull strength reduction.

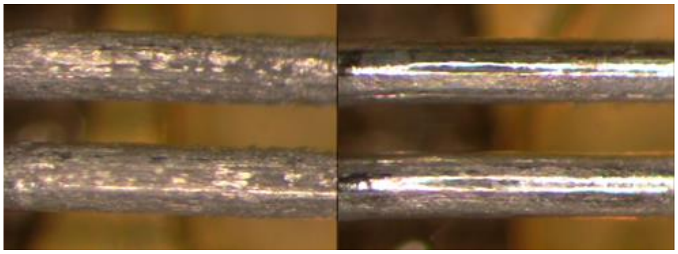

Figure 5 Corrosion check after 1000 hours of 85°C/85% RH testing with normal aluminum wire

C. *Corrosion Resistant Aluminum Wire*

Figure 6 shows that the Au-Al intermetallic compounds are approximately 4 µm thick after 2000 hours of 175°C high temperature storage testing with corrosion-resistant wire. This is vast improvement compared to the approximately 4.5 µm thick Au-Al intermetallic with normal aluminum wire after only 1000 hours at 175°C (Figure 7). No sign of Kirkendall voids is found after thermal aging.

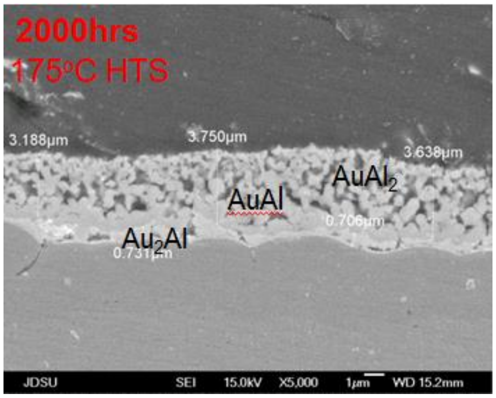

Figure 6 Intermetallic check of Al-Au after 2000hrs of 175°C High Temperature Storage

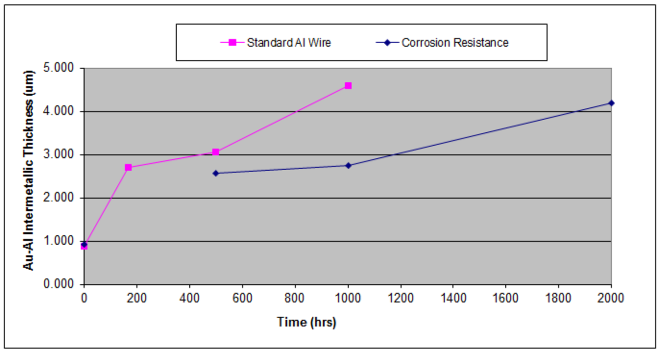

Figure 7 Au-Al intermetallic thickness comparison between normal and corrosion resistant wire

Figure 8 demonstrates the effectiveness of corrosion-resistant aluminum wire with shiny appearance after 2000 hours of 85°C / 85% RH damp heat testing. This is a significant improvement compared to normal aluminum wire as shown in Figure 5 for just 1000 hours at 85°C / 85% RH. The pull strength is also improved with less than 10% reduction compared to time zero.

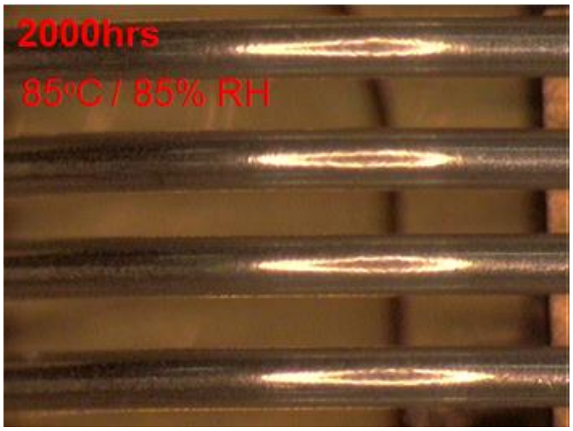

Figure 8 Corrosion check after 2000 hours of 85°C/85% RH testing with corrosion resistant aluminum wire

III. Conclusion

A thick wire bonding solution has been successfully developed with copper and aluminum wire at room temperature for high power semiconductor laser packaging. This is crucial for cost reduction and improved wall plug efficient. Both the Cu/Au and Al/Au systems are highly reliable with excellent intermetallic layer and no Kirkendall voids formation. Finally, corrosion-resistant aluminum wire exhibits slower intermetallic growth, higher pull strength in addition to corrosion-resistance which exceeds reliability requirements.

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