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Ultrasonic Bonding of Ag Ribbon on Si Wafers With Various Backside Metallization

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ABSTRACT

Ultrasonic ribbon bonding has gained much attention due to the endeavor of achieving higher module performance in power electronic packaging. Among all the ribbon materials, Ag ribbon is a promising candidate due to its superior electrical properties. However, research which has reported the bonding of the ribbon on chip side is scant. Thus, in this study, the authors carried out bonding of the Ag ribbon on various types of metallized wafers to examine the feasibility of Ag ribbon, simulating the bonding scenario on the chip side in power modules. Results revealed that bonding of the Ag ribbon is feasible on those wafers metallized Ag on top. The authors also discussed the implications for the bondability of Ag ribbon with different types of metallization layers.

KEYWORDS

Ag Ribbon, Bonding Strengths, Si Wafer Backside Metallization, Ultrasonic Bonding

INTRODUCTION

Semiconductor chips are connected electrically to other components or systems in order to function. Such electrical connections are critical to electronic packaging and are accomplished by utilizing various forms of conductors to build up the signal or power connection pathways within a single package. Therefore, the bonding should provide a decent electrical interconnection that will not decay with time, while providing excellent performance of the semiconductor chips. Wire bonding is one of the standard interconnection techniques for electrically connecting microchips to the terminal of a chip package or directly to a substrate (Harman, 2010). Generally, the wire bonding technology can either be categorized by the wire bonding method (ball–wedge or wedge–wedge) or the bonding mechanism that creates the metallic interconnection between wire and substrate (thermo-compression, ultrasonic or thermosonic) (Jung et al., 2019).

Each bonding method entails a range of advantages and drawbacks; therefore, the decision to use one of them has to be made with consideration of the application. A recent industry survey has shown that about 90% of all electronics packages and assemblies are made of ball bonds, while the rest are produced with wedge bonds. The most established material for bond wire is gold alloy (>

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90% Au), usually doped with elements such as beryllium to increase the strength and ductility so as to improve properties such as wire loop height, elongation at break, temperature strength, breaking load or tensile strength (Simons et al., 2000). Meanwhile, different types of bond wires have been designed to adapt to technological niches such as high-current applications, assemblies restricted to low processing temperatures, or bonds with enhanced mechanical strength. Some common bond wires are aluminum wire, palladium coated copper wire, and silver-alloy wires. The wire sizes are typically 0.6 to 2 mils; however, for power devices, larger diameter wires ranging from 5 to 20 mils in diameter are used for a higher current carrying capacity (Zhou et al., 2023). Thermosonic bonding enhances the reliability of previous mechanisms by preheating the bonding wire in advance of the ultrasonic cycle to reduce cracking issues in Si chips. As an alternative to thermocompression bonding, thermosonic bonding has been broadly used for Au gold wire bonding of ICs in both packages and multichip modules. In power electronic packaging, however, most of the wire diameters are around 300–500 μm due to the high voltage and current applied (Liu, 2012). The formation of the ball bond in the thermosonic bonding method becomes rather tricky when the wire diameter increases, and this challenge has given rise to efforts to achieve bonding through ultrasonic bonding (Maeda & Takahashi, 2013). Ultrasonic bonding can be used to join a wide variety of metals (Neppiras, 1965), rendering it a popular bonding technique today. However, the operation requires careful handling to prevent mechanical damage, and the acoustical properties of the joining materials can change causing variations in strength.

As for wire materials, metals with high electrical conductivity and a high diffusion rate, such as Cu (Lim et al., 2014), Au (Wulff et al., 2003), Ag (Chen et al., 2022), and Al (Schneider-Ramelow & Ehrhardt, 2016), are commonly used for wire bonding. Among these metals, gold wire is a very attractive choice because this metal is fully utilized in ultrasonic, mechanical force, and heat processes. Moreover, Au wire is profoundly electrically conductive, almost a significant degree more so than other metals. Au has much higher oxidation resistance than other metals and is relatively soft, which is important for delicate surfaces.

The characteristics of Cu are very similar to those of Au. Cu wire bonding was the first option adopted to replace Au wire bonding in semiconductor packaging. The great interest in Cu is driven by its lower cost, better electrical resistivity, and tool readiness. Cu wire bonding has been implemented in recent nano-scale semiconductor packaging in industry due to its conductivity properties and cost effectiveness (Chauhan et al., 2013; Zhou et al., 2023). Cu wire began to emerge in the mid-1990s and was not initially deployed in large scale manufacturing due to its vulnerability to wire corrosion and oxidation (Xu et al., 2009). Currently, many researchers are dedicated to studying the reliability issues of copper wires (Lim et al., 2021; Mathew et al., 2022; Qin et al., 2019). As a solution to the drawbacks of Cu wire bonding, different types of Cu alloys have been introduced since 2010, some examples being Pd-doped or Pd-coated Cu wires for various applications and humidity reliability performance (Clauberg et al., 2010.). Despite this limited use, Cu wire bonding is not an ultimate bonding wire solution for advanced power module packaging due to its intrinsic material hardness, which could cause chip cratering during ultrasonic bonding (Gross et al., 2016). This drawback has led to the widespread usage of Al wire.

Similar to Au and Cu, Al has low electrical resistance, making it suitable for interconnections among the components of electronic packaging (Schneider-Ramelow & Ehrhardt, 2016). Al wires can also be used for conductive interconnections, but only ultrasonic energy and mechanical force play key roles in shaping the Al bond. It is noteworthy that Al allows interconnections to be constructed on temperature-susceptible materials, as it does not demand the high temperature conditions generally required for Au and Cu wire bonding. Furthermore, Al is utilized in most of chip metallization. Al wire is likewise very desirable for bonding on chip surfaces to form homogeneous bonding interfaces, which are highly correlated to the joint integrity of wire bonds. However, the low melting point and poor mechanical properties of Al have limited its usage in some applications, especially in power electronics with high reliability demands, leading to a new search for wire materials.

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