Preface

Wire bonds form the primary interconnections between an integrated circuit chip and the metal lead frame in semiconductor packaging. Wire bonding is considered to be a more cost-effective and flexible interconnect technology than flip–chip interconnects. As of 2013, more than 90 % of semiconductor packages were interconnected by wire bonding.

Gold (Au) wire has been used for wire bonding in the electronics industry for more than 50 years because of its high tensile strength and electrical conductivity, high reliability, and ease of assembly. However, due to its high cost and continuously rising market prices, alternative wire bonding materials have been considered. Copper (Cu) is one of the most preferred alternative materials for wire bonding because of its cost advantages over Au. For example, in March 2013, the cost of Au hovered around US$1,610/oz, compared to US$3.45/lb of Cu. Cu wire also offers advantages in terms of higher mechanical strength, lower electrical resistance, slower intermetallic growth (with an aluminum (Al) pad), and higher thermal conductivity than Au. The higher electrical and thermal conductivity of Cu, compared to Au, enables the use of smaller diameter wire for equivalent current carrying capacity or thermal conductivity.

Replacing Au wire with Cu wire in the wire bonding process presents many challenges. Parameter adjustments for ball bond formation, stitch bond formation, and looping profile are needed. Cu is harder than both Au and Al, and therefore bonding parameters, including bonding force, must be kept under tight control. Since Cu wire is highly prone to oxidation, inert gas such as nitrogen or forming gas must be used during the bonding process. In some cases, wire manufacturers have used palladium (Pd)-coated Cu wire, which is more resistant to oxidation than bare Cu wire. Also, since bare Al pads run the risk of being damaged by Cu wires due to the high hardness of Cu and the high bonding force required, the industry has adopted Al pads that are thicker than those used in Au wire bonding, as well as pads with nickel (Ni)-based finishes.

Some semiconductor companies have adopted Cu wire bonding technology into their assembly and test sites, and are running Cu wire bonding production across a wide range of package types. For example, in May 2012, Texas Instruments shipped around 6.5 billion units with Cu wire bonding technology in its analog, embedded processing, and wireless products. Texas Instruments also reported that all seven of its assembly and test sites are running Cu wire bonding production across a wide range of package types.

Because of the ongoing trends towards Cu wire bonding, the differences between Au and Cu wire bonding need to be understood in order to modify the manufacturing processes and reliability tests. The bonding metallurgies, process variations, and reliability of Cu and PdCu wires bonded on various surface finishes need to be evaluated. This book provides an understanding of Cu wire bonding technology, including the bonding process, bonding tools and equipment, PdCu wires, surface finishes, wire bond–pad metallurgies, wire bond evaluation techniques, and reliability tests on Cu wire-bonded parts.

The book is organized into nine chapters. Chapter 1 gives an introduction to Cu wire bonding technology. The advantages of Cu over Au, such as lower cost, higher mechanical strength, and higher electrical and thermal conductivity, are discussed. The chapter describes the adoption of Cu wire bonding in the semiconductor industry, as well as future projections for its usage.

Chapter 2 presents the wire bonding process, including the influence of process parameters on the wire bonds and bond process optimization. Bonding parameters such as ultrasonic power, ultrasonic generator current, electric flame-off current, firing time, bonding force, and temperature are discussed. The potential defects and failures that could arise during the bonding process and the bonding damage induced by tools are explained.

Chapter 3 explains the wire bonding metallurgies for Cu and PdCu wires. The most common variations are bare Cu wires, PdCu wires with Al bond pads, and Ni/Au bond pads. The interfacial metallurgies of bare Cu wire on Al-, Ni-, and Cu-based bond pads are examined. Comparisons are made between the interfacial intermetallics, Au–Al, Cu–Al, and Cu–Au, at the bond–pad interface. The growth rates and electrical, mechanical, and thermal properties of the intermetallics are presented. The bond–pad interfaces for Ni-based finishes, such as Au–AuNi, Au–AuPdNi, Cu–AuNi, and Cu–AlPdNi, are also assessed.

Chapter 4 discusses the evaluation of wire bonding performance. The criteria for good bonds are described, along with pre- and post-bonding inspection techniques. Wire bond functionality tests, such as bond accuracy tests, electrical resistance measurements, and material characterization of wire bonds are covered. Destructive and nondestructive mechanical tests, shear tests, and pull tests to evaluate the wire bond strength are discussed. The industry standards and best practices for wire bonding quality assurance and testing methods, and the common reliability tests for wire bonds, are also explained.

Chapter 5 covers the thermal reliability tests conducted on Cu wire bonds. High-temperature storage tests on Cu and PdCu wires on Al-, Au-, and Ni-based pads are discussed, and reliability test data are provided. Comparisons are made between the high-temperature storage strengths of Cu and PdCu wires. The effect of high-temperature storage on Pd distribution, as well as its effect on wire bond strength, is discussed. Cu wire bond reliability under thermal cycling and thermal shock testing is also presented.

Chapter 6 discusses the effects of high humidity and high temperature, as well as high current densities, on the reliability of Cu wire bonds. Reliability data are provided from humidity reliability tests, pressure cooker tests, and highly accelerated stress tests on Cu wire-bonded parts. Comparisons are made between the humidity-related reliability of Cu and PdCu wire bonds. Electromigration tests to evaluate the reliability of wire bonds under high electrical current are also presented.

Chapter 7 examines the pad materials and finishes for wire bonding. Cu wire bonding on Al and Cu pads is discussed. The common pad finishes, including NiAu, NiPdAu, PdAu, electroless nickel immersion gold (ENIG), electroless nickel/electroless palladium/immersion gold (ENEPIG), and electroplated silver are considered. The effect of the thickness of surface finish layers on bond strength is also explained. The chapter also discusses the effects of surface treatment on the reliability of wire bonds. The sources of contamination on bond pads, including fluorine, chlorine, carbon, oxygen, silicon, and titanium, are examined, along with their influence on wire bond reliability. The effect of lead surface contamination and pad surface roughness on wire bond strength is considered. The surface treatments, including organic coating to prevent pad oxidation and plasma cleaning to remove surface contaminants, are also explained.

Chapter 8 provides an overview of the concerns with Cu wire bonding and the industry's solutions to these concerns. Although Cu wire bonding is gaining widespread acceptance in the industry, there are a few challenges associated with it that need to be overcome. Cu wire bonding poses concerns related to Cu's hardness, propensity to oxidize, and sensitivity to corrosion, as well as the wire bonding process, bonding in specialized packages, and low yield. The industry solutions to these problems, such as the use of thicker Al pads than are used in Au wire bonding, Ni-based pad finishes, specialized capillaries, palladium-coated Cu wires, and bonding in an inert gas atmosphere, are also discussed.

Chapter 9 provides recommendations for the wire bonding process, including the use of oxidation prevention technology and bonding process parameter optimization. Recommendations for the use of PdCu wires and bond pad surface treatments, including organic coating and plasma treatments, are given. The recommended surface finishes for the pad and lead frames are listed. The microstructural characterization conducted on bond–pad interfacial intermetallics, including interfacial IMC thickness, mechanical and electrical properties of IMCs, and recommended aging temperatures for IMC characterization, is explained. Recommendations are provided for wire bond inspection and strength evaluations, reliability, qualification, and failure analysis.

Appendix A provides data on the mechanical, electrical, and thermal properties of Cu, Au, and PdCu wires. The wire bond process parameters and bond strength test data for Cu and PdCu wires for both first and second bonds are given. The reliability risk matrix for Cu and PdCu wires is provided as well. Appendix B summarizes some of the key patents in the industry, including patents for PdCu wires, Cu wire bonding methods, designs of bonding tools, underpad structures for

Cu wire bonding, and inert gas for oxidation prevention during bonding with Cu wire.

This book is intended for electronics assemblers and manufacturers transitioning to Cu wire bonding technology. It also serves as a knowledge base for readers who are interested in learning about Cu wire bonding, who will carry out evaluations of the Cu wire bonding process, and who will conduct qualification reliability tests on various packages to facilitate the mass production of semiconductor electronic products.

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