Platinum Wire Wedge Bonding: A New IC And Microsensor Interconnect

JOSEPH V. MANTESE and WILLIAM V. ALCINI

Electrical and Electronics Engineering Department
General Motors Research Laboratories
Warren, MI 48090-9055

Ultrasonic ball or wedge bonding of Au or Al has been the traditional method for making electrical interconnects between die and chip header for most Integrated Circuit (IC) and microsensor devices. Electrical interconnections made from these materials may, however, be unsuitable for some device applications. Some microsensors (e.g., oxygen exhaust gas sensors) can be subject to temperatures as high as 900 °C in both oxidizing and reducing atmospheres, conditions for which the properties of Au or Al are unsuitable. In this report we describe a new means of making electrical connections between die and chip header. Interconnects are made by using a conventional wire bonder to ultrasonically wedge bond 0.032 mm diameter Pt wires to both Pt and Al thin films. Interconnects made in this manner are remarkably strong, as compared with Au wire bonds, with pull strengths of ~13 g. Electrical measurements show contact resistances of <0.05 Ω. Annealing tests show that bonds made to thin metal films of Pt on Ti on sapphire show no appreciable signs of electrical or mechanical degradation after anneals at 900 °C for 1 h in pure oxygen.

Key words: Wire bonding, platinum, ultrasonic bonding

INTRODUCTION

The transition from thin film processing to large scale manufacturing processes occurs at the time a die is mounted to a suitable header and electrical interconnects between the die and package are made. While packaging issues may be limiting factors in device performance and applications, consideration of such issues are often neglected in initial device designs. We believe that device packaging is of crucial importance, and that packaging issues should be resolved well in advance of mask design, especially if the devices are to be exposed to unconventional temperature or chemical environments.

Ultrasonic wedge or ball bonding of Au or Al wire are the traditional means by which dies are electrically connected to header pins. Aluminum is typically wedge bonded to contact pads at ambient temperatures, whereas Au wire must be ball or wedge bonded at elevated temperatures, ~150 °C.

Though both Au and Al wire have been used as reliable interconnects for Integrated Circuit (IC) and microsensor devices, materials issues prevent their universal use for all microsensor and IC devices. The low melting point of Al, 660 °C, and corresponding low annealing temperature, 440 °C, limit the temperature range over which it may be used as an interconnect material. In addition, accelerated Al oxidation occurs as the temperature of the bond material is elevated, causing degradation of the contact. Though Au does not oxidize, and has a higher melting point, 1064 °C, than Al, its 710 °C annealing temperature restricts its use for device applications to a limited temperature range.

Under the hood electronics, using SiC as the semiconductor base material, are currently under development. Integrated circuits made from SiC would be required to maintain both their mechanical and electrical integrity over the temperature range -150 °C to 200 °C for an extended period of time. Such ICs may require a new interconnect material for packing. In addition, there are currently under development a number of automotive sensors which are to be placed in the engine exhaust where temperatures may exceed 900 °C and the chemical environment varies from oxidizing to reducing. It is thus desirable to have a non-oxidizable material which has a high melting point and which can be wedge bonded or ball bonded to contact pads.

Platinum is an ideal material for microsensor and IC interconnects. It does not oxidize. It melts at 1872 °C and anneals at a temperature considerably higher than either Au or Al, 1250 °C. Its yield strength, 10 MPa, is lower than either Au, 200 MPa, or Al, 100 MPa, suggesting that it plastically yields easily enough for traditional wedge bonding. There have, to our knowledge, been no reports of successful Pt wire wedge bonding.

In this letter we examined the feasibility of 0.032 mm diameter Pt wire wedge bonding to a variety of substrates coated with approximately 300 nm of Pt or Al. Bond strengths for all materials to which successful bonds could be made were ~13 g and were limited primarily by the strength of the Pt wire. Electrical measurements showed that the contact resistance to metal film bonding pads were less than 0.05 Ω. Platinum wire bonds made to metal films of Pt on Ti on sapphire showed no appreciable signs of degradation after annealing for 60 min at 900 °C in oxygen.
EXPERIMENTAL

Single crystal 25 mm diameter disks of randomly oriented sapphire and 76 mm, <100> oriented Si wafers were used as substrate materials for this work. The sapphire was cleaned by degreasing in a 1:1:1 boiling solution of trichloroethylene, acetone, and isopropyl. The Si wafers were cleaned in a mixture of hydrogen peroxide and ammonia hydroxide followed by a hydrogen peroxide and hydrochloric acid bath. When required, the Si wafers were oxidized at 1000°C in dry oxygen. Oxide thicknesses were typically 160 nm.

DC magnetron sputter deposition of Pt and Ti could be done on either of the two types of substrates. Substrates could be heated, using quartz lamps, prior to metal deposition. Yttria stabilized zirconia (YSZ) could also be sputtered onto the substrates using rf diode sputtering. Aluminum was e-beam evaporated onto the substrates. Sample annealing was done at 900°C for 60 min in an oxygen atmosphere. The 300 nm metal coating was convenient for our concurrent research work. We found that thicker coatings work equally well.

All bonding was done with a commercial wedge bonder fitted with a ferroelectric transducer assembly. A 40427-0008-167 Microswiss wedge bonding tool was used with the tool length set at 1.460 cm. Alpha-Pt wire, 0.032 mm in diameter, was used in this study.

Ultrasonic bonding of Pt wire to thin films of Pt or Al was possible at a variety of wire bond settings. When using a fixed bonding force of 20–40 g, the optimum force for the materials described, successful bonding to 300 nm films of Pt on <100> Si was possible for the range of bonding times and powers shown in Fig. 1. Optimum bonding occurred for bonding times of 0.35–0.65 s and ultrasonic powers of 0.55–0.75 W. There is some variability in the position of the optimum bonding lobe due to tool wear, the type of substrate material used and other unknown parameters. This variability could produce shifts in the lobe position by ±0.15 s and ±0.35 W.

Successful Pt wire wedge bonding was critically dependent upon proper tool length. The 1.460 cm length which was used for this work was 0.051 cm longer than that specified by the manufacturer of the transducer. The effective mechanical impedance of the transducer and wedge assembly was measured by replacing the power generator and feedback circuitry of the transducer assembly with a constant voltage sweep oscillator. The current was measured as a function of tool length and frequency. Two resonant frequencies (local maxima in power absorption) were found for a tool length of 1.460 cm. One resonance occurred at 64.2 ± 0.28 kHz and the other at 62.5 ± 0.07 kHz. Ideally, when the ultrasonic generator of the transducer assembly is used, it locks onto only one of the two resonant modes. The generator output, however, is not a very clean sine wave and the signal distorts during bonding, and thus both modes may be excited. When the tool length was set to 1.460 cm, analysis of the power transferred by the two resonances, showed that the 64.2 kHz resonance could deliver ~6 times more power to the wedge bonding tool than the 62.5 kHz resonance.

The 64.2 kHz resonance was the only observable tool resonance when the tool length was set to 1.410 cm, the specified length. This resonance mode was obviously due to the scrubbing action of the wedge tool on the die surface. This is the mode that the manufacturer designed the bonder to operate at. The mode shape is well characterized, and is a transverse bending beam mode. The lower resonance, at 62.5 kHz, developed as the tool length was increased to 1.460 cm. The mode shape of the tool at this tool length and resonant frequency is complex and is probably not a simple transverse bending mode. Experimental determination of this and other complex mode shapes was beyond the resources and feasibility of the researchers, and as described by the manufacturers is an extensive undertaking. The mode shape of this second mode is unknown but may be related to a pounding action of the tool on the wire. Both resonant modes appear to be essential to form successful bonds.

For tool lengths longer than 1.460 cm a third resonant mode, in addition to the two high frequency resonances, develops at 61.0 ± 0.67 kHz. This mode is very detrimental to Pt wire bonding. The third mode was observed to arise from a side-to-side motion of the bonding tool, which resulted in the wire sliding from under the tool.

Optimum bonding occurred by adjusting the tool length so that there was maximum power adsorption in the 62.5 resonance (pounding action) without significant decrease in the 64.2 kHz resonance (scrubbing action) and no appreciable excitation of the 61.0 kHz resonance (side-to-side action). In Fig. 2 is plotted the power absorption in the primary (64.2 kHz) and two secondary (62.5 kHz and 61.0 kHz) modes as function of tool length. As can be seen from this plot, optimum bonding occurs at a tool length of ~1.460 cm.

Figure 3 shows a platinum wire bond made to a thin Pt film 300 nm thick. The applied force on the wire was usually adjusted to produce a width spread

![Fig. 1](image-url) -- Ultrasonic bonder settings found to yield good Pt wire to metal film bonds. Arrows indicate possible shifts in lobe position due to variations in substrate material and tool wear. Tool length was 1.460 cm. Bonding force was 20–40 g.