A Critical Review of Wirebond Visual Inspection Criteria

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ABSTRACT

Wirebond engineers and technicians primarily rely on three means by which to evaluate the integrity and reliability of a wirebond interconnect. Destruct/non-destruct pull test, ball shear, cross-sections, intermetallic coverage under the ball are tests used to evaluate the mechanical strength as part of process development and in line process controls. Reliability testing and evaluation involves these same tests after prolonged environmental exposure such as, temp cycling, burn-in, humidity testing etc. according to standards such as AEC-Q100. Much has been written about the above. A third and very important consideration in wirebonding is visual inspection of the deformed wire after wirebond formation. The amount of wire squash-out, placement of the bond on the pad relative to nearby circuitry, looping profiles and heel integrity are all very important aspects of wirebond interconnect inspection. Poor workmanship can lead to noncompliant bonds per visual inspection criteria and can directly impact the reliability of the finished product. Bond pad inspection prior to bonding is also a critical aspect that is often overlooked. Historically, MIL-STD-883 has served as a baseline set of visual specs related to wirebond, and package assembly in general. Many company quality documents reference MIL-STD-883 TM 2017 and TM 2010 and/or cut and paste the bond inspection criteria into internal documents. This paper critically reviews the wirebond visual inspection criteria contained in MIL-STD-883 relative to the requirements of a fully optimized modern day wirebond process.

Key Words: MIL-STD-883, Visual Inspection, TM 2017, TM 2010, Workmanship Standards eBook Hybrids Microcircuits RF/MMIC Modules workmanship standards

INTRODUCTION

MIL-STD-883 (Test Method Standard for Microcircuits) contains the visual inspection criteria for assembly and packaging of hermetic microcircuits, including wirebond visual inspection criteria. MIL-STD-883 is a collection of test methods, the defacto standard for many companies and industries around the globe. It's a publically available document [1].

MIL-STD-883K w/CHANGE 2, dated 22 February 2017 contains two important test methods with the latest wirebond visual inspection criteria. They are TM 2017.12 (Hybrid Visual Inspection) and TM 2010.14 (Monolithic Visual Inspection). Although intended for military systems operating between -55 and 125 C, these visual inspection standards are used and copied into quality documents at many companies outside of the mil community including: Telecom/ optoelectronics, medical devices, microwave, oil and gas, commercial space, and other high reliability industrial applications. TM 2017 and TM 2010 contain the bulk of the wirebond inspection criteria. These standards are owned by the DLA (Defense Logistics Agency Land and Maritime). However, they are reviewed and updated by volunteers working in committees within JEDEC (Joint Electron Device Engineering Council), specifically JC-13 Government Liaison. They are consensus documents and it can be a long and arduous task to revise/update. The last major revision to TM 2017 was in 2015. TM 2010 has not had a major update for many years. In some areas the inspection criteria is lenient and in others perhaps overly restrictive. The MIL-STD- 883 inspection criteria applies to both auto and manual, gold and aluminum wire. These test methods were not written with copper wire in mind!

BALL BONDS

The ball "squash" factor is an important visual indicator as to how well the bond was made. The ball bond is made when the capillary captures the FAB (free air ball) and using pressure and ultrasonic energy deforms the ball to make the bond. Mil specs require the deformed ball to be 2X to 5X the wire diameter (Fig 1). 2X is considered a good lower limit. Although many reliable automated processes form nail head bonds using .8 mil wire and the ball squash is less than 2X. A small deformed ball relative to the wire diameter reduces the bonded area and will decrease strength. The upper end of this squash factor limit of 5X is very lenient. It's difficult to squash a ball more than 5X and even a 4X squash factor indicates overbonding and possible damage to the IC.

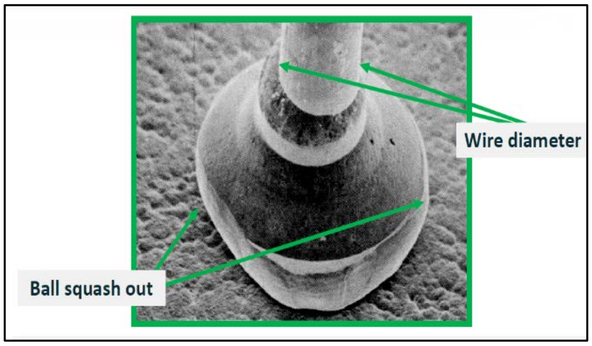

Fig. 1: Mil Spec Ball squash criteria is 2X to 5X the wire diameter

Ball squash that is less than 3.5 X is typical of a high yielding ball bonding process [2].

"Golf club" (Fig 2) is part of a wirebonder's vernacular. This occurs when the FAB is not centered under the capillary during the downward movement of the bond head. But not all "golf clubs" are visual rejects. Mil standard criterion requires the wire exit to be within the periphery of the ball and the wire exit must be within the periphery of the bond pad (Fig 3). As shown in Fig 2 a wire exit outside the perimeter of the ball is a reject because the capillary may have impacted the die surface, which is problematic when bonding to pads on GaAs/GaN components where the fracture toughness is ½ that of silicon.

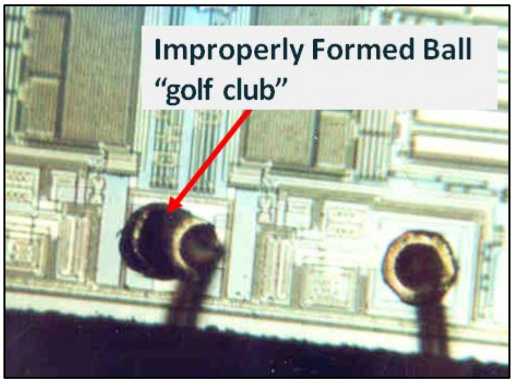

Fig. 2: Golf Club bond reject wire exit outside of ball perimeter

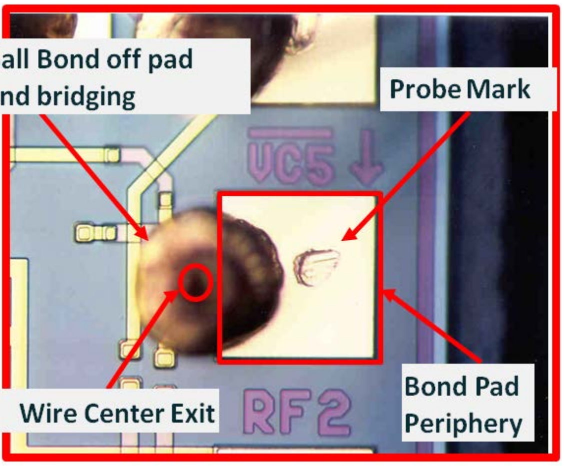

Fig. 3: Reject…Wire exit is outside bond pad perimeter

The second half of the ball bond is referred to in the mil specs as the crescent and is part of the "tailless" bond. Early ball bonders used a hydrogen flame off to cut the wire at second bond and create the free air ball, where the process actually created two balls. These tails protruding from the substrate then had to be manually removed. The "tailless" bond made with an EFO (Electronic Flame Off) and sharp cut face of the ceramic tip was a significant advancement at the time, but the nomenclature of the tailless bond remains in the mil specs today. The crescent, sometimes referred to as stitch, is placed on the leadframe or substrate and the squash factor is depicted in Fig 4. This second bond criteria is difficult to inspect when a gold wire is placed onto a gold plated or thick film substrate. Similar to the max ball squash criteria, it's lenient yes, but a good idea to guard against skidded or skewed bonds

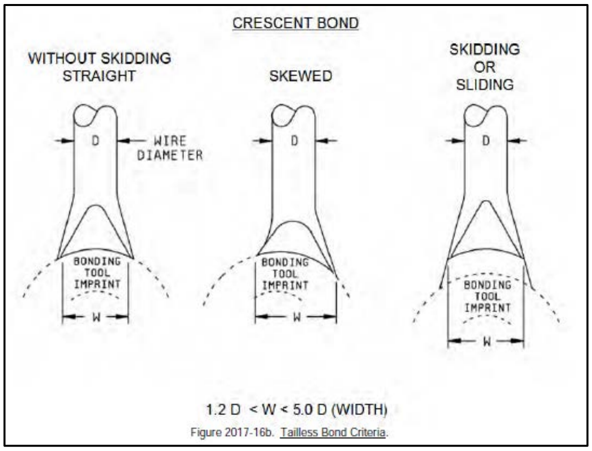

Fig. 4: Crescent bond squash out criteria

The ultrasonic energy delivered to the tip of a tool has a direction to it. It's a vector in a sense. Piezoelectric crystals convert the electrical energy into vibrational energy and the best crescent bonds are made when the energy flows down the length of the wire. Operators on manual machines can make bonds by bonding in the 3 and 9 o'clock position. However, the ultrasonics at the tip roll across the width of the wire and form a sub optimized "skewed" looking crescent as shown in Fig. 5. Most automatic wirebond equipment compensate for this effect.

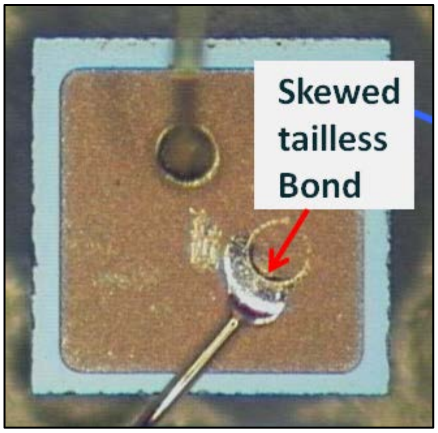

Fig. 5: Skewed bond footprint

Another important inspection point, prohibited by the mil specs, is bonding a gold wire crescent onto an aluminum IC pad. Two potential reliability problems related to this type of bond are: 1) excessive intermetallic growth and associated Kirkendall voiding as the limited amount of gold at the IC pad will be quickly be consumed into the intermetallic formation and, 2) potential mechanical damage to the IC as the ceramic capillary contacts the fragile die surface. The ball normally acts as a cushion at first bond.

SECURITY BONDS

A security bond (Fig. 6) is a type of compound bond where a ball is placed on the crescent bond to secure and reinforce the original bond. This can be done manually or with automatic bonders that can place a ball and shear it off at the neck. If done correctly, a security bond can be an effective process to improve the strength and reliability of the second bond, provided it is not a solution for “no sticks” and surface contamination. For example, thick films often have a natural depression down the middle of the trace, which can cause the crescent bond to break due to the uneven surface. Soft board material such as Duroid and FR-4 tend to show improved pull test results with security bonding. The MIL-STD-883 inspection criteria for security bonds is focused on centering the ball up on the heel of the crescent. The reinforcement or security bond must be monometallic and centered 75% on top of the original bond.

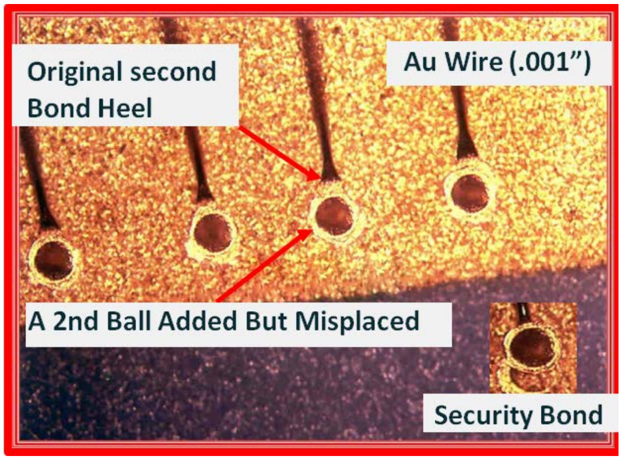

Fig. 6: Incorrect security bond…ball placed on tool mark instead of heel at second bond

WEDGE BONDS

Fine wire wedge bond inspection criteria was recently tightened up in TM 2017. For gold or aluminum wire the max squash out on the deformed wire is 2X as shown. A squash factor W, less than 1.2 times or greater than 2.0 times the wire diameter is cause for reject (Fig 7). For most high yield wedge bond processes a squash factor of 1.3 to 1.6 X is generally in the optimum range.

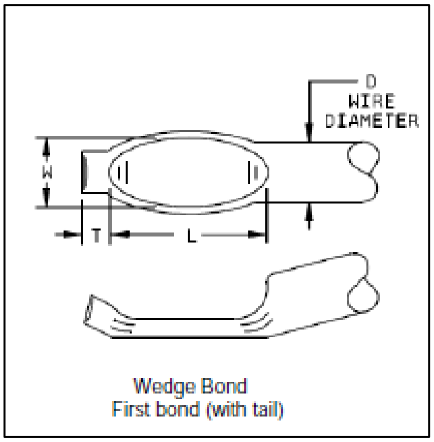

Fig. 7: Wedge bond squash criteria
$1.2D < W < 2D$

Approaching the upper spec limit of 2X, especially for aluminum wire, is cause for concern. Heel cracks at the junction of a bond pose a reliability risk [3]. A one mil aluminum wirebond squashed out 2X, or 2 mils, potentially has a heel crack. This heel crack (Fig 8) may or may not be observable at the recommended 30 to 60X magnification range for inspection. There are many causes for heel cracks e.g. too much power/force, not hitting flat or too sharp a bend radius on the wedge tool. Excessive looping can also be a cause for heel cracks at the junction of first bond. Aluminum wire work hardens. It's like a coat hanger, give it a couple of bends and it breaks.

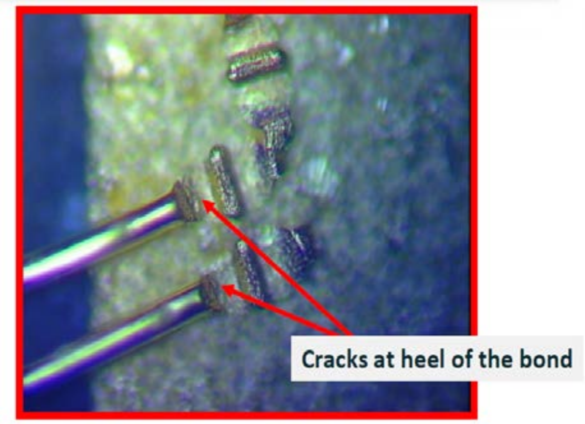

Fig. 8: Heel cracks in a 1 mil AU wedge bond 200X

The first bond made in a wedge bonding process produces a little tail. Although sometimes short and hard to see, it's important to have some amount of wire tail protruding out in front of the wedge tool. Mil specs limit this tail to no more than 2X the wire diameter and the concern is excess tail can break loose and become a source of loose FM (foreign material) inside the hermetic cavity. Long tails that extend over unpassivated metal runs is also not allowed, especially in the microwave community. Tail length on an optimized high volume wedge bonding process is tightly controlled.

GENERAL WIREBOND CIRTERIA

Both TM 2017 and TM 2010 contain a section on general wirebond inspection criteria. This includes criteria regarding placement of the wire bond relative to the pad. In most cases the bond foot can be up to 50% off the pad and still be within the inspection limits. With this upper boundary the area bonded under the foot is reduced by 50%, which negatively impacts the strength of the connection. Other general criteria focuses on bonding on or near foreign material. In a hybrid package bonds on foreign material including die attach epoxy or eutectic flowout, or bonds placed within 5 mils of die attach material or the resin that often bleeds from the epoxy is prohibited. Inside a monolithic device, as per TM 2010, up to 25 percent of the bond foot may be located on die mounting material. Other inspection criteria are focused on wires crossing wires, excess loops, or no loop at all. It's required that all wires have some loop for stress relief. Exactly how much loop is dictated by the design, but given the mismatch in TCE for the myriad of materials used, and the temp range of interest, it's critical to have some loop for stress relief.

PROBE MARKS

Before a wirebond of any kind is attached to an IC or MMICs (monolithic microwave integrated circuit), the operator/inspector must inspect the device for excessive probe marks, bond pad contamination, corrosion or staining that may be evident at the bond pad. The inspection criterion that pertains to bond pads prior to bonding is contained in the high mag section of TM 2010 beginning in para. 3.1.1. Recommended magnification for bond pad inspection is 75X to 150 X. Wafer probe marks greater than 25% of the bond pad area and expose underlying passivation are cause for rejection. Heavy probe marks (Fig 9) may damage the IC and missing metal underneath a bond weakens the interconnect [4]. This criterion is a function of bond pad area so in some cases the pad may fail the inspection criteria, but there is still plenty of room to bond on undisturbed metal. In other cases, such as the gate pad on a microwave FET or schottky diode, every bit of bond pad is needed to form a reliable bond.

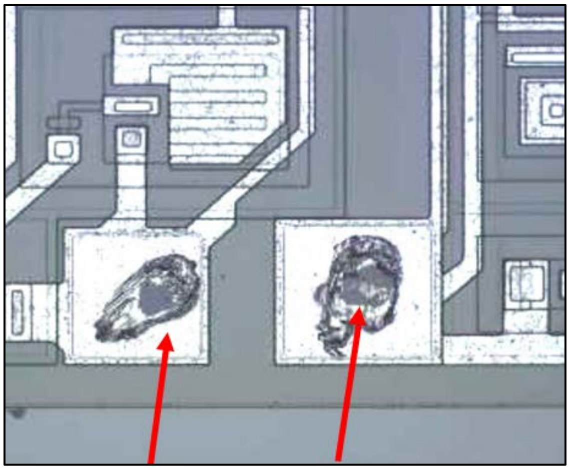

Fig. 9: Excessive probe marks from wafer test

The rinse water from the wafer sawing process may be contaminated and cause corrosion or the saw may chip into the pad area. Particulates at the bond pad are another concern. Most bond pads are opened up by etching away a layer of polyimide or glassivation. This is a precise wafer fab cleanroom operation and if not done correctly a thin layer of glass [5] or polyimide may remain at the pad and cause bondability/reliability issues.

TM 2017 vs TM 2010

The wirebond inspection criteria referenced in Mil-STD-883 is contained in either TM 2017 (Hybrids and multi-chip modules including microwave devices) or TM 2010 (Monolithic i.e. single chip in a package). There is some additional inspection criteria contained in MIL-STD-750, but the 750 standard pertains specifically to discrete packaged semiconductor devices. MIL-STD-750 is a cousin of MIL-STD-883.

The wirebond inspection criteria are not consistent in TM 2010 vs TM 2017. This creates confusion in the industry as QE's/inspectors struggle to understand which criteria to apply. The significant difference between the wirebond criteria in TM 2017 vs TM 2010 is the squash factor on a wedge bond. TM 2010 allows for a 3X max squash factor vs. TM 2017, which is only 2X the wire diameter.

TM 2010 contains additional bond inspection criteria not addresses in TM 2017. For example, wirebonds placed at or near the entering/existing metallization stripe at the bond pad would be cause for rejection as shown in Fig 10. When bond tails prevent visibility of the connecting path to the bond periphery and the metallization immediately adjacent to the bond tail is disturbed the inspector must reject. The concern is the bond foot contacting the glassivation and opening the metal run entering into the pad.

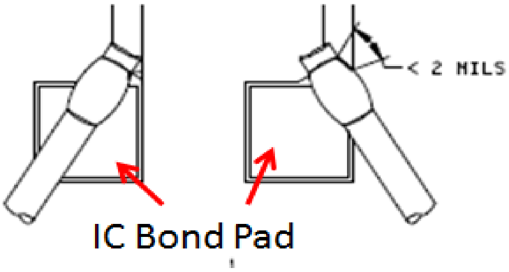

Fig. 10: TM 2010 bond inspection criteria

SUMMARY

MIL-STD-883 wirebond inspection criteria were developed over many years and are intended to cover a broad range of technologies. The visual inspection criteria contained in both TM 2017 and TM 2010 contains a lot of wisdom and serves to this day as the defacto standard. For QML (Qualified Manufacturers Listing) suppliers it is a contractual requirement, but for most it's a guideline and a great starting point. In some cases the inspection criteria is lenient and in others spots overly restrictive. It's important to have a clear understanding of the baseline requirements. In many cases the inspection criteria needs to be further tailored and enhanced with clear colored pictures to meet the customer requirements. [6]

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