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Experimental Study and Modeling of Microwave Bond Wire Interconnects

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Abstract

We present a comprehensive characterization and study of various wire bond interconnect configurations for microwave integrated circuit packaging. Wire bond interconnects with two different bond types (ball-crescent and wedge), two different loop types (tight and loose) and various lengths are fabricated and experimentally characterized. We show the performance comparison of these configurations and develop an electromagnetic and a simple lumped-element equivalent circuit model.

Introduction

Despite the emergence of new microwave interconnect technology, wirebonding remains a dominant conventional low cost, high reliability and high manufacturability chip connection technology [1]. When used as connections to Microwave Integrated Circuits (MIC) in a packaged module, bond wires exhibit parasitic effects that impact the module performance. Therefore, there is a need for an accurate high frequency characterization. Extensive investigations both experimentally [2-3] and theoretically using numerical approaches [4-7] so far only focus on some specific wire bond configurations. In this paper, we present a comprehensive characterization of ball-crescent and wedge bond wire interconnects as functions of wire lengths with tight and loose wire loops above the ground plane. In summary, the original contributions of this paper are:

- Experimental characterization of various types of wire bond interconnects as functions of lengths with two different bond types and loop heights.
- Development of an electromagnetic and a simple lumped element equivalent circuit model.
- Performance comparison of various configurations.

Design of Experiments

Bond wire test structures with 1 mil diameter gold wire are fabricated using thermosonic ball and wedge bonders on 10 mils thick Probe Point ™ microstrip to coplanar waveguide on alumina substrates [8] as shown in Figure 1. Such configuration is desirable to enable on-wafer measurement using air coplanar probes. We investigate the wire bond performance as functions of lengths, bond shapes (wedge and ball-crescent), and loop heights (tight and loose) as shown in Figure 1. The wedge wire bond is fabricated by the wedge-bonder and ball-crescent wire bond is fabricated by the ball-bonder. The tight loop wire bond is approximately 20 mils high above the ground plane, while the maximum height of the loose loop wires are approximately 40 mils high above the ground plane.

The adapters are attached on a gold plated brass as a ground plane using a conductive epoxy after which the microstrip ends of the adapters are wirebonded. We performed TRL calibration [9] from 1.5 GHz to 40 GHz to de-embed the adapters and established the reference planes at the microstrip ends of the adapter so that the measured result contains only the wire bond under test. The S-parameter measurement of the test samples was performed using HP8510C network analyzer.

Experimental Data

An electromagnetic model for tight-loop wire bonds is developed and simulated using Method of Moment algorithm [10]. The wire bond is modeled as two strips with rectangular cross section on air having width equal to the actual wire diameter, connected to each other on their edges by via. The wire bends at the end of the wire connected to the microstrip line are also modeled by vias on air connecting the both strips to the microstrip line. A simple lumped-element electrical model shown in Figure 2 is developed based on the experimental results. The model consists of an ideal inductor L in series with a resistor R representing the wire inductance and loss due to metalization as well as radiation loss at the wire bends respectively. The capacitor C at the input and output ports represents the substrate capacitance between the microstrip line onto which the wire is bonded to the ground plane and is assumed to be constant since all wires are bonded on the microstrip lines in a similar manner. The inductor L' at the input and output port represents end inductance caused by the bonds and is assumed to be constant as well for every configuration. The superimposed plots showing a good agreement among the measured and EM simulation as well as the result obtained from the circuit model is shown in Figure 3. The extracted values of L', C and R corresponding to the 25 mil tight ball-crescent bond wire are 50 pH, 17.5 fF and 0.3 Ω, respectively. The minimum and maximum wire inductance L for this configuration that corresponds to the best and worst case performance is 0.60 nH and 0.65 nH, respectively. The measured best and worst case result in Figure 3 is obtained from ten identical samples. From Figure 3, the maximum insertion loss variation of approximately 0.5 dB occurs at 40 GHz. The measured loss per unit length of the four configurations, tight and loose ball crescent and wedge types plotted in Figure 4 indicates that the tight loop wedge topology exhibits the lowest loss, 0.02 dB better than that of the tight ball-crescent at 40 GHz. On the other hand, the loss performance of the loose ball-crescent bond wire is only slightly higher than that of the wedge configuration.

Conclusion

We have presented a comprehensive characterization approach for various types of wire bonds on air connecting two microstrip lines. Experimental data indicates that tight loop wedge wire bonds show a slightly better loss performance than the tight -loop ball-crescent wire bonds. The loose loop wedge and ball-crescent wire bonds, on the other hand show a comparable performance. More data for different wire lengths to verify the performance trends and analysis on the variability due to manufacturing tolerances are available and will be presented at the conference.

Acknowledgement

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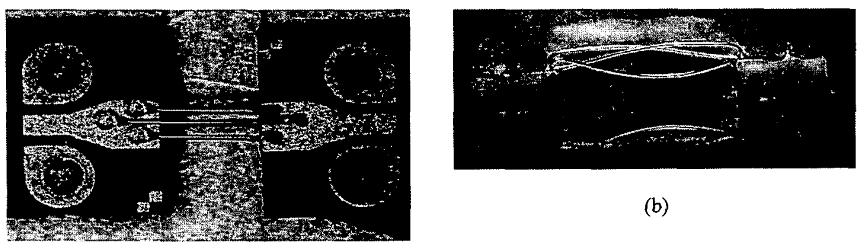


(a) (b)

Figure 1. Top (a) and side (b) view of a tight loop ball-crescent bond wire test structure connecting two microstrip lines on alumina substrates.

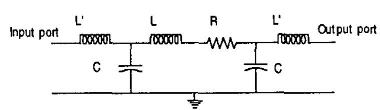
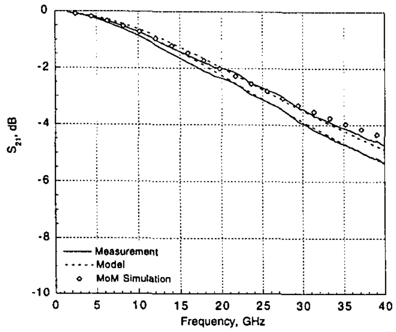
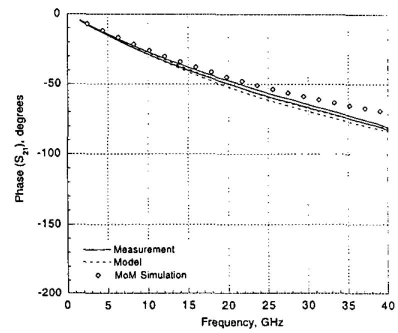


Figure 2. A simple lumped element circuit model for bond wire.



(a)



(b)

Figure 3. Measured, EM simulated and circuit modeled best and worst case insertion loss performance of a single 25 mil tight loop ball-crescent bond wire.

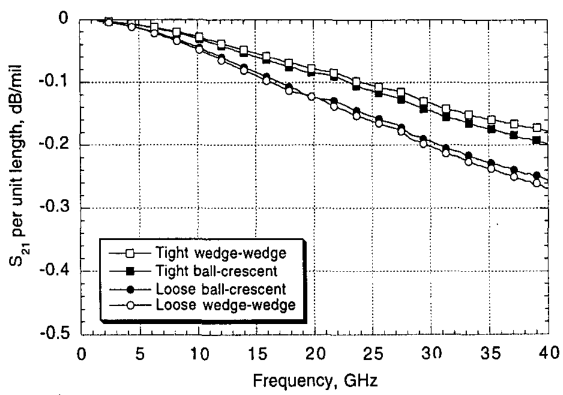


Figure 4. Measured loss per unit length of wire bonds extracted from 25 mil wire bonds.