Parasitic Impedance Analysis of Double Bonding Wires for High-Frequency Integrated Circuit Packaging

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Abstract—**Double bonding wires separated by an internal angle have been characterized in a wide range of frequencies using the Method of Moments with the incorporation of the ohmic resistance. For a 30° internal angle, the calculated total reactance is more than 35% less than that of a single bonding wire due to the negative mutual coupling effect of different current directions. The radiation effect at high frequencies has been observed decreasing the mutual inductance between the angled bonding wires, whereas for parallel bonding wires it greatly increases the mutual inductance.**

I. Introduction

Modern semiconductor devices and circuits such as Optoelectronic Integrated Circuits (OEIC's) and Microwave Monolithic Integrated Circuits (MMIC's) have high operating frequencies at which bonding wires limit their performance as a dominant parasitic [1]. Multiple wire bonding has been widely used to reduce the parasitic inductance at high frequencies. Since the parasitic inductance strongly depends on the separation and the internal angle between bonding wires, it should be accurately characterized and taken into account for design and packaging of the high frequency devices. However, no theoretical and experimental characterizations of multiple bonding wires have been published in the open literature. Direct measurement of the parasitic inductance has difficulties of calibration and error modeling associated with the crosstalk and radiation effects of the tiny geometry. A single bonding wire has been analyzed by the Method of Moments (MoM) with the incorporation of the conductor loss [2]. In the wideband analysis, significant radiation is observed at high frequencies, which is expected to make high mutual coupling between multiple bonding wires. Two parallel bonding wires coupled with a separation have been characterized over a wide range of frequencies using the Method of Moments [3]. High mutual coupling enhanced by the radiation effect has been observed at high frequencies.

In this letter, two bonding wires separated by an internal angle have been characterized using the MoM with the incorporation of the ohmic resistance. For a 30° internal angle, the calculated total reactance is 35% less than that of a single bonding wire in a wide range of frequencies. The radiation effect at high frequencies has been observed decreasing the mutual inductance between the angled bonding wires, whereas increasing the mutual inductance for parallel bonding wires [3]. Consequently, the angled multiple bonding wires have much less parasitic reactance, especially at high frequencies, and are very profitable for high-frequency device packaging.

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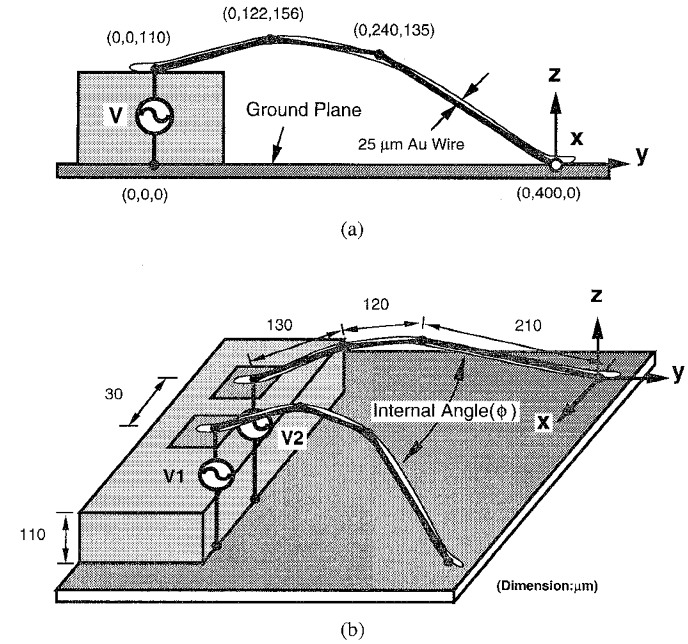

Fig. 1. Geometries of (a) a single wedge-bonded wire and (b) double wedge-bonded wires with an internal angle (ϕ) for a 100-μm-thick GaAs device.

II. Modeling and Analysis

Multiple wire bonding for high frequency devices usually use wedge bonding method since wedge-bonded wires have smaller bonding loop and consequent lower inductance than ball-bonded wires. In Fig. 1(b), two identical wedge-bonded wires with an internal angle (ϕ) connect two bonding pads to a perfect ground plane. Two bonding pads are separated by 30 μm and are excited by individual voltage sources (V_1, V_2) in order to calculate the mutual coupling effect between bonding wires. The typical shape of a gold bonding wire with a 25 μm diameter in Fig. 1(a) has been statistically obtained from real wedge bonding experiments of a 100-μm-thick GaAs device and modeled by three linear wires for the MoM calculations.

In the MoM calculations, total length of a bonding wire is kept to 460 μm and the internal angle is widely varied.

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Each bonding wire is segmented by 13 pulses and the axial line current is expanded and tested by the same pulse functions using the Galerkin's method [2], [4]. The perfect ground plane is replaced by the image bonding wires. Since small conductor loss of the gold bonding wire enhances the radiation due to the slow-wave effect [5], the ohmic resistance calculated by the PEM [2] is uniformly distributed on the pulse segments as lumped impedance loading for the MoM calculations. The dielectric effect of the semi-insulating GaAs substrate is neglected because of the low-impedance bonding wires.

The even and odd input impedances (Z_e, Z_o) are, respectively, calculated for an even and an odd excitation of two voltage sources (i.e., $V_1, V_2 = 1$ V and $V_1 = 1$ V, $V_2 = -1$ V). Then, the self inductance (L) and the mutual inductance (M) are calculated by $\mathrm{Im}(Z_e + Z_o)/2\omega$ and $\mathrm{Im}(Z_e - Z_o)/2\omega$, respectively. The real part of the input impedance is associated with the ohmic and radiation losses. The radiation resistance is approximately obtained from the input resistance of ideal conducting wires.

III. Calculated Results

Total input impedance of the double bonding wires has been calculated from one half of the even input impedance $(Z_e/2)$ for the shunt wire connection. Fig. 2(a) shows the calculated total input impedance for a 30° internal angle compared with those of a single bonding wire and parallel bonding wires spaced by the 30-μm bonding spacing. The resistance (R) is very small compared to the reactance (X), but its frequency is rapidly increasing due to the radiation effect enhanced by the ohmic loss [2]. The angled bonding wires have less radiation resistance because of their different current directions. The parasitic reactance of the angled bonding wires is about 35% less than that of a single bonding wire in the whole frequency range. The parallel bonding wires, however, have 15% less reactance than the single bonding wire. The reactance reduction of the angled bonding wires is more significant at high frequencies (about 45% reduction at 100 GHz) due to the following negative mutual coupling effect.

The self inductances calculated for various types of bonding wires are rapidly increasing at high frequencies due to the radiation effect as shown in Fig. 2(b). Slightly higher self inductance of the angled bonding wires is associated with the radiation-enhanced proximity effect between the angled bonding wires, which effectively increases total magnetic flux by the current induction. Mutual inductance of the parallel bonding wires is increasing due to the radiation effect as well. However, the angled bonding wires have much less mutual inductance decreasing to the increasing frequency. The high reduction of mutual inductance is related to different current directions of the angled bonding wires. In Fig. 1(b), the longitudinal current components in y-direction have positive mutual coupling, whereas the lateral current components in x-direction are opposite each other and, hence, they experience a negative mutual coupling. In addition, the negative mutual coupling becomes dominant at high frequencies because radiation directions of the lateral currents are mostly in x-direction but the longitudinal currents radiate the fields in y-direction as a small loop ant [4]. Therefore, the total mutual inductance is decreasing and becomes negative at very high frequencies as shown in Fig. 2(b). Static self and mutual inductances shown in Fig. 2(b) are calculated by axially dividing the angled bonding wires with 20 segments and applying the static parallel wire modeling [6] commonly used in CAD software. They are in very good agreement with the MoM results at very low frequencies, but they have significant discrepancy at high frequencies due to the radiation effect and the negative coupling effect. It has been observed that the negative coupling effect and consequent reactance reduction of the angled bonding wires are increasing to the increasing internal angle (ϕ) as shown in Fig. 3.

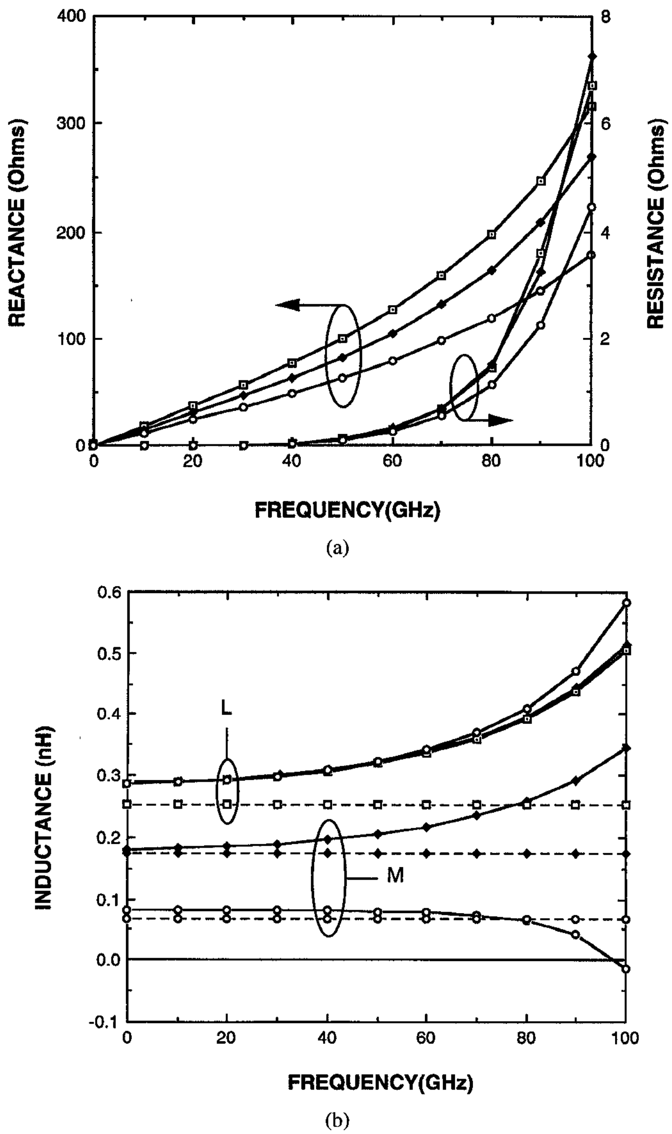

Fig. 2. (a) Calculated total input impedance and (b) self and mutual inductances (L and M) of the single bonding wire, parallel bonding wires with a 30 μm spacing, and the double bonding wires with a 30° internal angle. —□— single bonding wire; —◆— parallel bonding wires; —○— angled bonding wires; —— MoM; – – – static.

IV. Conclusion

Double bonding wires separated by an internal angle have been characterized using the MoM with the incorporation of

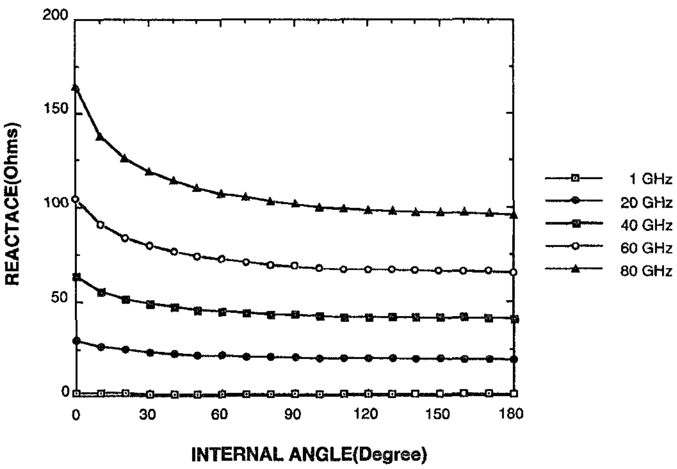

Fig. 3. Calculated total reactance to internal angle variation.

the ohmic resistance. For a 30° internal angle, the calculated total reactance is more than 35% less than that of a single bonding wire in a wide range of frequencies due to the negative mutual coupling effect between lateral current components. The radiation effect at high frequencies has been observed decreasing the mutual inductance between the angled bonding wires, whereas for parallel bonding wires it greatly increases the mutual inductance. Consequently, the angled multiple bonding wires have much less parasitic reactance, especially at high frequencies and, hence, they are very profitable for high-frequency device packaging.

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