Coaxial transitions for CPW-to-CPW flip chip interconnects

W.C. Wu, E.Y. Chang, C.H. Huang, L.H. Hsu, J.P. Starski and H. Zirath

A novel coaxial transition for CPW-to-CPW flip chip interconnect is presented and experimentally demonstrated. To realise the coaxial transition on the CPW circuit, benzocyclobutene was used as the interlayer dielectric between the vertical coaxial transition and the CPW circuit. The coaxial interconnect structure was successfully fabricated and RF characterised to 67 GHz. The structure showed excellent interconnect performance from DC up to 55 GHz with low return loss below 20 dB and low insertion loss less than 0.5 dB even when the underfill was applied to the structure.

Introduction: Flip chip interconnect has been proven to be a low-cost alternative with superior performance in all aspects for microwave applications. In the conventional flip chip architecture, bump parameters and pad sizes are optimised for better transition characteristics. High impedance line and staggered bumps have been proposed and demonstrated to achieve broadband transition performances [1]. Another proposed special design in [2] for the better electrical shielding purpose was to use multiple ground bumps arranged in an annular form as the vertical transition at the flip chip interconnect. This was called pseudo-coaxial vertical transition. However, it was still not a real coaxial transition at the vertical interconnect. Previously we have proposed and successfully fabricated the coaxial-type transition for the flip chip interconnect [3]. In this Letter, the perfect coaxial transitions have been designed and successfully fabricated by using the benzocyclobutene (BCB) dielectric as the interlayer material between the coaxial ground ring and the signal line of the coplanar waveguide (CPW) line. The fabricated structures have been RF characterised up to 67 GHz and show low return and insertion loss even when the underfill was injected into the structure. With the proposed novel structure, significant signal loss induced by the underfill can be avoided for frequencies at least up to 55 GHz.

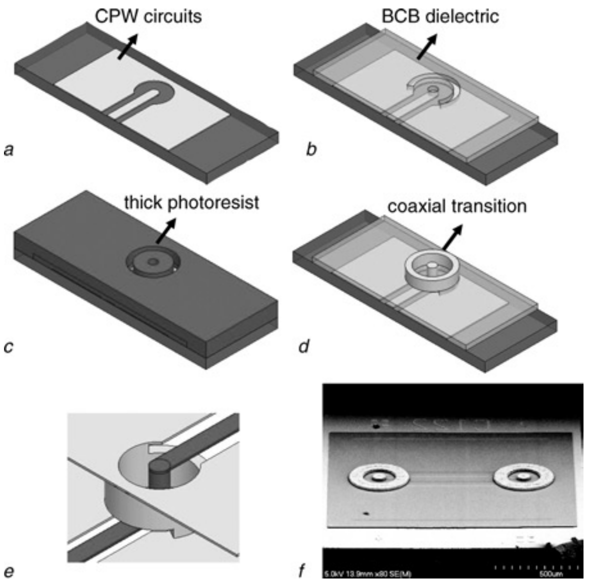

Fig. 1 *Main steps of fabrication processes (not to scale)*

Fabrication: For the proposed coaxial transition in the flip chip structure, the fabrication of the coaxial bumps is of critical importance. To realise the perfect coaxial transitions between the CPW circuits on the chip and on the substrate, a dielectric layer must be used to support the ring-shaped ground bump and prevent the coaxial ground bump from touching the CPW signal line. BCB was chosen here as the dielectric layer because of its superior performance at high frequencies. Fig. 1 shows the main steps of the fabrication procedures. Al_2O_3 and GaAs were the materials for the substrate and the chip, respectively. The interconnect metal was gold and formed by electroplating. After the Au CPW lines of 3 μm were electroplated, as shown in Fig. 1*a*, BCB were coated as the dielectric layer. The photoresists were then patterned on the BCB layer as the etching mask for the following dry etching process. After RIE etching with the CF_4 and O_2 gas mixture, the BCB film was patterned and then cured at 250°C for 1 h to achieve cross-linking for the polymer, as shown in Fig. 1*b*. Ti (300 Å) and Au (500 Å) layers were deposited using an E-gun evaporator as the seed layer for the electroplating of the vertical coaxial bumps. To define the positions and dimensions of the coaxial transitions bumps, thick photoresists were patterned, as shown in Fig. 1*c*. By controlling the electroplating current density and time, the Au coaxial bumps of the required height were attained. After electroplating, the thick photoresists and the seed layer were then removed to form the final structure, as shown in Fig. 1*d*. The coaxial bump transitions were fabricated on both sides of the Al_2O_3 substrate and the GaAs chip. Fig. 1*f* shows the SEM image of the fabricated chip with the fabricated coaxial bumps. The fabricated chip sample was then bonded to the substrate sample using the thermo-compression method to accomplish the final interconnect structure. The detailed view of the perfect coaxial transition is shown in Fig. 1*e*.

Design of coaxial transition: The coaxial-type transition has the advantage of better field confinement and therefore can achieve good isolation at the vertical transition [3], i.e. it can provide good electric shielding for the vertical signal transmission. Generally, underfill is needed for the flip chip structure to ensure the reliability of joints during the temperature cycling by reducing the thermal stress due to the CTE (coefficient of thermal expansion) mismatch of different materials. However, it degrades the performance of the flip chip assembly [4], because of the higher dielectric constant (usually 3–4) and the higher dissipation factor (approximately 0.05 at 10 MHz) as compared to the air. The underfill mainly induces the additional transmission loss to the final assembly and changes the effective dielectric constant of the transmission line on the MMICs.

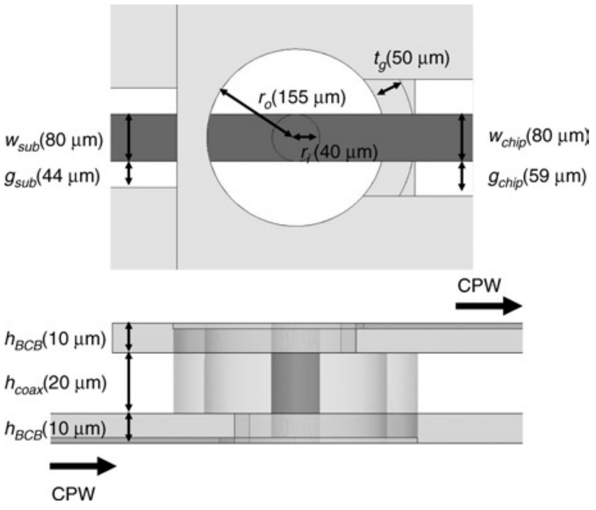

Fig. 2 *Physical parameters of designed coaxial transition*

In the proposed coaxial transition structure, the ring-shaped ground bump together with the centre signal bump forms a perfect coaxial transition structure having better field confinement over the conventional G-S-G transition architecture. Furthermore, because with the ring-shaped ground wall the injected underfill stays outside of the coaxial structure, it can provide good isolation and prevent the perturbation of the underfill for the signal transmission in the coaxial structure.

The coaxial transition structure was optimised using the simulation tool CST for the 3-D electromagnetic field analysis. The goal of the design was to achieve low reflection below 20 dB at the interconnect with a bandwidth from DC to 60 GHz. The thickness of the Al_2O_3 substrate and GaAs chip were 254 and 100 μm, respectively. The characteristic impedances (Z_0) of the Au CPW lines on the chip and the substrate were 50 Ω ($w_{sub} = w_{chip} = 80$ μm, $g_{sub} = 44$ μm, and $g_{chip} = 59$ μm). The CPW length on the chip was 900 μm, and the CPW length on the substrate was 700 μm. The total length of the interconnect structure was 2300 μm. Fig. 2 shows the final optimised design details of the coaxial transition structure, where $r_i = 40$ μm, $t_g = 50$ μm,

$r_o = 155\ \mu m$, $h_{BCB} = 10\ \mu m$, and $h_{coax} = 20\ \mu m$. After design, the demonstrated interconnect structures were then fabricated using the in-house developed process.

S-parameters results: The demonstrated flip chip interconnect structures using the proposed coaxial transitions were RF characterised up to 67 GHz by the on-wafer probing measurement system with the Agilent PNA. Fig. 3 shows the simulated and measured transmission coefficients of the demonstrated structures with and without the underfill injected ($\varepsilon_r = 3.5$ and $\tan\ \delta = 0.02$ at 10 MHz). The simulated and measured results show good agreement. The flip chip interconnect structure with the proposed coaxial transitions demonstrates excellent performance up to 67 GHz. In the case without underfill injection, the return loss was less than 20 dB and the insertion loss was within 0.7 dB from DC to 67 GHz, which clearly demonstrates the feasibility and potential of the proposed coaxial transition for the flip chip interconnects. In the case with the epoxy-based underfill injection, the return loss was still less than 20 dB from DC to 55 GHz. Above 55 GHz, the return loss and insertion loss became worse but was still less than 10 dB for the return loss at 67 GHz. The shift in the frequencies of the minimum reflection resulted from the change of the effective dielectric constant of the CPW line due to the existence of the underfill. The return loss slightly increased because of the impedance mismatch induced by the change in the effective dielectric constant. The two structures with and without underfill injection showed comparable insertion loss from DC to 55 GHz. Above 55 GHz the sample with the underfill injection showed an increase in insertion loss, and the return loss also increased. At 60 GHz, the return loss was 13.7 dB, and the insertion loss was 0.9 dB. The measured results demonstrated excellent potential for the proposed coaxial transition to be used for the flip chip interconnects up to 60 GHz.

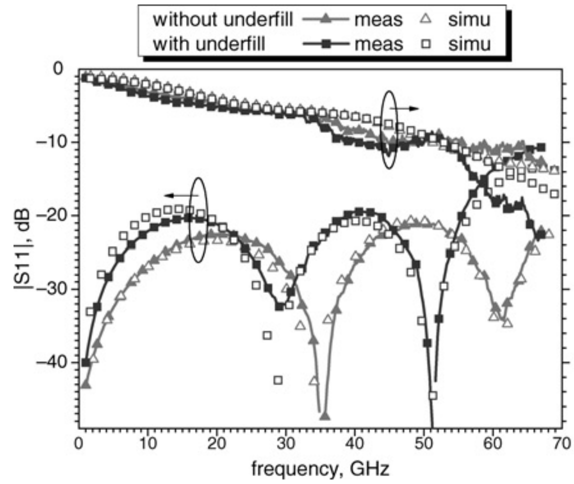

Fig. 3 *Comparison of simulated and measured transmission coefficients of demonstrated structures with and without underfill injection*

Conclusion: Novel coaxial transitions for the flip chip interconnects have been proposed and experimentally demonstrated to have excellent transition performance with low return and insertion loss from DC to 67 GHz at least. Even with the underfill injection, the flip chip structure using the proposed coaxial transition still showed excellent interconnect performance. This study reveals the great potential for the application of the coaxial transition as the various interconnect transitions at very high frequencies.

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W.C. Wu, E.Y. Chang, C.H. Huang and L.H. Hsu (*Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 300, Taiwan, Republic of China*)

E-mail: williamwu.mse90g@nctu.edu.tw

J.P. Starski and H. Zirath (*Department of Microtechnology and Nanoscience, MC2, Chalmers University of Technology, Göteborg SE-412 96, Sweden*)

W.C. Wu: Also with the Department of Microtechnology and Nanoscience, Chalmers University of Technology, Göteborg, Sweden

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