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Miniaturized hybrid Antenna combining Si and IPD™ technologies for 60 GHz WLAN Applications

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***Abstract*—This paper presents the design of a packaged antenna including glass substrate. A square patch antenna is implemented on glass substrate exploiting IPD™ technology, and excited by a coupling slot implemented on BiCMOS B9MW technology (Low Resistivity (LR) Si – ρ = 12 Ω.cm). The described solution solves the interconnection problem between Silicon Integrated Circuits (ICs) and the antenna. The excitation structure is integrated on Silicon substrate using conventional process, thus reducing insertion losses usually caused by flip-chip or assembling techniques. The second advantage of this solution is the co-integration of the coupling slot with the RF front-end. This permits to match the antenna input impedance to the PA output impedance, with consequently improved power budget efficiency. This antenna achieves a simulated gain of 5 dBi at 60 GHz and a relative bandwidth of 8 %. A preliminary antenna on alumina and glass substrates has been realized in order to verify the flip-chip assembly process. The measurements results are in good agreement with simulation.**

Keywords-millimeterwave; hybrid antenna; System in Package; silicon substrate; IPD™ technology.

I. INTRODUCTION

At millimeter wave frequencies, high data rate applications such as Wireless HDMI require low cost and low power System on Chip (SoC) for addressing mass-market products and expectations. Thanks to the recent progress of Integrated Circuits (ICs) on CMOS or BiCMOS Silicon technologies, the complete integration of the RF front-end on a single chip is now achievable [1]. Furthermore, due to the small operating wavelengths considered (e.g. 5 mm in air @ 60GHz), a higher integration level can be ensured by co-integrating the antenna. Besides quite a high gain value (14dBi) is expected for Wireless HDMI applications compliant with the different established standards (ECMA, 802.15.3c [2], WirelessHD, WiGig Alliance). This application requires beamforming capabilities to prevent multipath effects generated by human presence. The use of antenna array is necessary for respecting these specifications. Due to the Silicon (Si) substrate characteristics (dielectric constant, loss tangent, thickness), integrated antennas exhibit quite low gain and reduced radiating efficiency [3, 4]. In addition, the implementation of antenna array on Si is not appropriate because of the high insertion losses of planar distributing network on Si as well as corresponding huge dimensions with respect to acceptable chip size (cost motivations). Thus, a hybrid integration technique appears as a good trade-off to report radiation elements and lossless feeding structures on an appropriate passive circuit supporting material, like glass substrate or fused silica [5, 6].

II. IPD™ TECHNOLOGY

In this paper, we propose to use the IPD™ (Integrated Passive Devices) technology from STMicroelectronics for the antenna substrate because it is suitable for antenna integration at millimeter wave frequencies due to its high quality factor (low dielectric constant and loss tangent) and its low production cost. The question lies therefore in the excitation of this antenna array and especially in the perfect control of the interconnections between integrated on chip excitation ports and antenna array input ports. If low gain completely integrated transceiver can be reasonably imagined on Si, as a single on-chip antenna can be used, higher directivity modules would require antenna array, and thus non-acceptable dimensions for being completely integrated. In addition, note that the packaging of such transceiver has to be simultaneously taken into consideration, as the packaging usually significantly contributes to the global cost of integrated modules, especially in the mmWave frequency range (alignment, loss and higher order modes spurious suppression constraints)

Consequently, the antenna array on IPD™ can be also considered as the upper part of the transceiver package, then minimizing cost thanks to its active contribution to the module performances. The interconnection between the Si chip and the array substrate becomes a fundamental parameter in the design and the optimization of such RF structures. Impedance matching, insertion losses and spurious mode excitations must be considered as challenging issues. In the literature [7, 8], flip chip techniques use bonding wires or bumps with compensation network to reduce interconnection losses.

In a previous work [9], we have presented an antenna array designed on IPD™ technology, mounted on the Si chip supporting excitation sources by means of μ-bumps (h = 100 μm). In this paper, we focus on the minimization of interconnection losses by exploiting coupling possibilities between an upper patch antenna reported on inverted glass substrate, and coupling slot directly integrated on Silicon, i.e. at the power amplifier (PA) output or at the low noise amplifier

(LNA) input (Fig. 1). This can be considered as an additional benefit of the proposed hybrid integration technique.

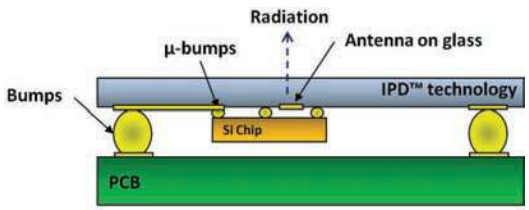


Figure 1. Side view of the mmWave package with the Si-IPD™ packaged antenna

III. Hybrid Si-IPD™ Antenna

The challenge of the hybrid integration is the interconnection between the ICs chip and the antenna part. The different proposed interconnection solutions generate insertion losses or impedance mismatches. So, we propose an alternative approach where the antenna is electromagnetically excited by a coupling slot directly implemented on the Si-chip. The radiating patch is implemented on the bottom face of the IPD™ material and the coupling slot is located on the M6 metallization layer of the BiCMOS B9MW technology (Fig. 2). The glass substrate (εr=4.6 – h=300µm) is also flip chipped by bumps on the silicon chip. The air gap located between the slot dipole and the patch is related to the bumps height (height=100µm after assembly).

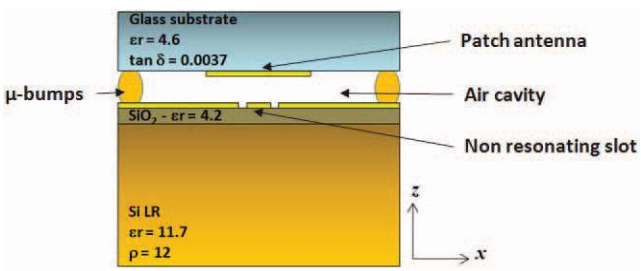
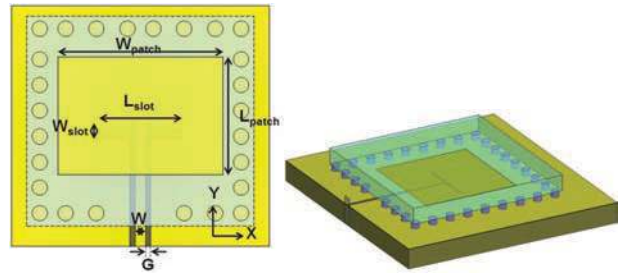


Figure 2. Side view of the Si-IPD™ packaged antenna.

The advantage of this solution is the compatibility between the propagation mode (CPW: coplanar waveguide) at PA output and dipole excitation. The ground of the CPW transmission lines and the coupling slot is assumed as the ground plane of the patch. Besides, the input slot impedance can be modified according to the PA output or LNA input impedance. Therefore, the antenna is perfectly inserted in this equivalent package, and ready to be optimally interfaced with active elements.

A first design of the coupling slot integrated on a BiCMOS process (Low Resistivity (LR) Si – 12 Ω.cm) from STMicroelectronics is proposed hereafter. The non-resonating slot is excited with a 50 ohms CPW line (W=30µm – G=9µm) and its dimensions are as follow: length L_{slot}=966µm – width W_{slot}=20µm. The slot is centered under the upper patch and is optimized in order to have the optimal magnetic coupling with the upper square patch (length L_{patch}=1.65mm – width W_{patch}=1.65mm). The proposed antenna is presented on Fig. 3.



(a) (b)

Figure 3. Top view (a) and 3-D view (b) of the Si-IPD™ packaged antenna.

A first simulation on HFSS™ with taking into account µ-bumps leads to a 30dB return loss at 60 GHz, and a 8% relative bandwidth @ VSWR=2 (57.4-62.2 GHz) (Fig. 4). This antenna presents a gain of 5 dBi and a F/B ratio of 17.5 dB at 60 GHz (Fig. 5). We obtain 55° and 66° half-power beamwidths for the E and H planes, respectively.

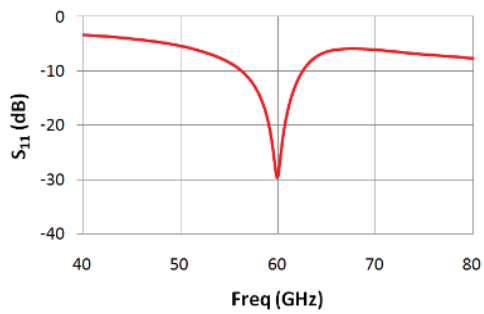


Figure 4. Simulated return loss of the Si-IPD antenna.

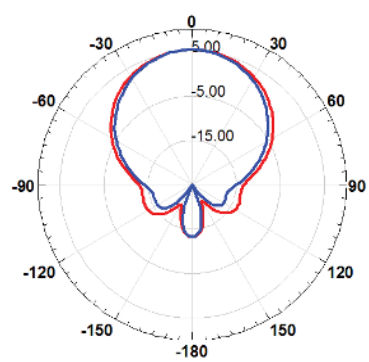


Figure 5. Simulated radiations patterns at 60 GHz: E (blue) and H (red) plane.

The mounting of this antenna is on-going and matching and radiation measurement results will be presented at the conference.

IV. Alumina-IPD™ Antenna for Process Validation

A preliminary study has been leaded to validate this concept exploiting Lab-STICC internal technology: replacing the silicon substrate by alumina substrate for the excitation structure, and glass substrate (IPD™ technology) by Rogers™ substrate for the patch antenna. This choice is justified by the

relative similarity of these supports (electrical characteristics quite similar). A comparative characterization procedure has been realized from Lab-STICC and STMicroelectronics test benches [10]. After the concept validation and characterization steps, the flip-chip technique has been validated with the realization of a hybrid antenna combining alumina substrate and IPD™ technology (Fig. 6).

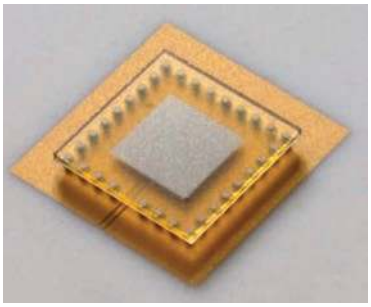


Figure 6. Photo of the Alumina-IPD antenna.

The air cavity located between the coupling slot and the patch depends on the µ-bumps diameter and reception pads dimensions implemented on alumina and glass substrates. In our case, a 100 µm air cavity height is obtained from a 140 µm µ-bumps diameter. The reception pads permit to achieve a high quality chip report with a perfect alignment. The return loss measurement of this antenna presents a very good agreement with simulation and confirms the assembly process quality (Fig. 7). A 25 dB matching is measured at 59.9 GHz with a 5% relative bandwidth @ VSWR=2. This antenna presents a simulated gain of 6.6 dBi and a F/B ratio of 13 dB at 60 GHz (Fig. 8).

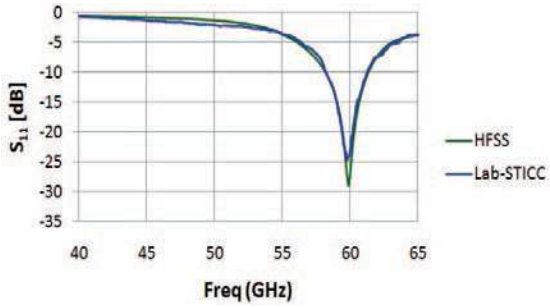


Figure 7. Measured and simulated return loss of the Alumina-IPD antenna.

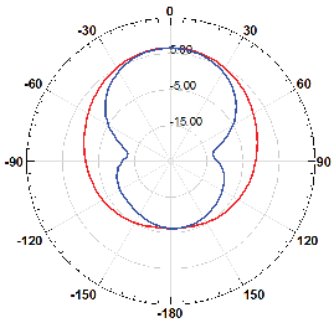


Figure 8. Simulated radiation patterns at 60 GHz: E (blue) and H (red) plane.

The radiation measurements will be presented at the conference.

V. Conclusion

A self-packaged antenna solution for 60 GHz communications is presented. The advantage of this antenna is mainly related to its excitation structure directly implemented on BiCMOS B9MW technology, thus allowing immediate interfacing with On-Chip ICs for beamforming and/or array weighting operations. The combination of low cost IPD™ technology allows a perfect integration of a low cost antenna solution in package. The elementary antenna achieves a simulated gain of 5 dBi at 60 GHz, and exhibits a 8% relative bandwidth. This antenna is being currently manufactured with the BiCMOS B9MW and IPD™ technology from STMicroelectronics – Crolles and Tours (France), respectively. The measurements results of this antenna will be presented during the conference. A preliminary antenna has been realized based on alumina and glass substrates. The measurements results present a good agreement with simulation and confirm the high quality of the flip-chip assembly process.

In order to increase gain and with respect to standard specifications for mmWave applications (Wireless HDMI), the hybrid Si-IPD™ antenna appears as a convenient solution for array implementation thanks to the limited dimensions of the patch element reported on a low cost substrate.

Acknowledgment

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