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THz Packaging Solution for Low Cost Si-based 40 Gb/s Wireless Link System

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***Abstract*—This paper presents an innovative low-cost transmitter solution aimed at improving telecommunication networks capacities in order to support the massive data traffic growth. Sub-THz frequencies > 200 GHz are considered to target at least 40 Gb/s. The proposed transmitter consists of a Silicon Photonic integrated sub-THz source and an industrial antenna integrated in HDI organic packaging substrate. As these components were experimentally evaluated, a real-time error free wireless data transmission of 10 Gb/s was successfully achieved and an antenna gain of 5.5 dBi was measured in the broadside direction from 220 GHz to 240 GHz (8.7% relative bandwidth). With the addition of a low-cost dielectric lens, a gain of 17 dBi was reached.**

***Index Terms*— silicon photonic IC, low-cost antenna in package.**

I. Introduction

To support the increasing amount of data to be transferred, telecommunication networks are being constantly upgraded though the deployment of high data-rate wireless systems. Data-rates above 40 Gb/s are today seriously envisioned to improve fronthaul and backhaul links' capabilities. As such, sub-THz frequencies above 200 GHz are investigated because they are able to access data bandwidths (BW) as wide as 100 GHz. In order to provide such BWs, the technologies that are chosen for the design of wireless links are of paramount importance. Volume production levels are also targeted, provided that low-cost and industrial technologies are used.

In this context, a possible solution for the transmitter consists in using Silicon Photonics (Si-Ph) technology. Indeed, this technology is compatible with CMOS, allowing industrial fabrication and aggressive integration levels. The photonic approach is based on photomixing, which works by converting an optical frequency beat into a sub-THz electrical signal thanks to a high-speed photodiode. This method represents a tremendous gain in terms of available bandwidth (> 50 GHz) and therefore seems promising for high data-rates transmissions [1].

Combining high sub-THz radiation performance and industrial antenna packaging techniques is a real challenge. Indeed, depending on the targeted link distance, the industrial antenna design should allow successful point-to-point transmission above 200 GHz. A solution would be to achieve a high gain antenna by using an antenna in package (AiP) as a focal source. This type of antenna is mostly appreciated by industrial players due to its compatibility with standard semi-additive fabrication process. Hence, a High-Density-Interconnect (HDI) organic packaging substrate seems appropriated in order to minimize RF losses while reaching aggressive integration levels [2]. Finally, associating this integrated antenna with a dielectric lens also helps in achieving a high enough antenna gain.

This paper presents our recent progress in the development of such a link, starting with a sub-THz source integrated in Si-Ph and an antenna integrated in HDI organic substrate. The targeted architecture of the global antenna system is represented in Figure 1, with respect to industrial assembly techniques. The Si-Ph IC will eventually be flip-chipped onto the HDI organic substrate inside which the antenna is integrated.

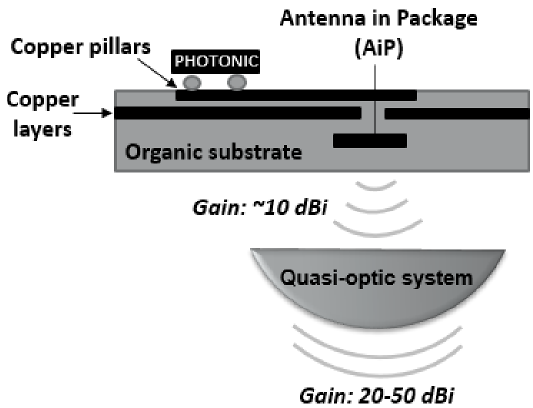

Fig. 1. Schematic view of the complet transmitter system architecture.

In the 1st paragraph, the design of the sub-THz source will be described as well as data communication transmission at 10 Gb/s. In the 2nd paragraph, the AiP and lens system will be presented and their measured broadside gain will be shown. Finally, the last paragraph will conclude on the work presented in this paper.

II. SUB-THZ SOUCE INTEGRATED IN SILICON-PHOTONICS

A. *Si-Ph IC design*

The first Si-Ph test structure, shown in Figure 2, was developed using STMicroelectronics' PIC25G technology platform [3]. In order evaluated their industrial high-speed SiGe photodiode, a 50-ohm matching network was incorporated to the design. The optical signal input is injected in the grating coupler, and the generated sub-THz signal is collected through optimized GSG pads as shown in Figure 2 [4].

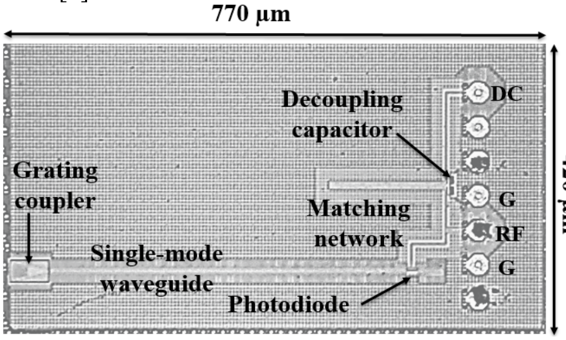

Fig. 2. Microscope image of the Silicon-Photonics photodiode integrated with its matching network.

B. *10 Gb/s measurements*

An indoor 50 cm wireless link was evaluated around 300 GHz using a data communication measurement setup with direct detection. The Si-Ph IC shown in Figure 2 was used at the transmitter side for photomixing. An ASK modulation scheme was generated to modulate the input optical signal and a Bit Error Rate (BER) Tester was connected at the receiving end of the setup to analyze the transmitted signal. As we can see in Figure 3, very clear eye diagrams were obtained at 4.25 Gb/s and 10.3125 Gb/s with a BER performance < 10^{-10}.

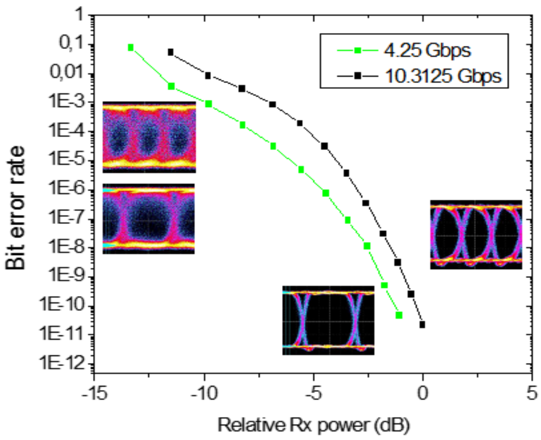

Fig. 3. BER measurement at 4.25 Gb/s and 10.3125 Gb/s with eye diagram images for indoor wireless ASK data transmission using the Silicon Photonic transmitter.

III. AIP-LENS DESIGN AND MEASUREMENT

A. *AiP design*

The HDI organic substrate used for the AiP consists of a dielectric stack-up with 4 metal layers. The dielectric core thickness was fixed to 100 µm to set the working frequency above 200 GHz and reduce surface waves propagation. A 2 by 1 array of aperture coupled patch antennas was designed to benefit from multiple frequency resonances. By doing so, a wide frequency BW was achieved. Finally, a grounded metallic cavity was added in order to take advantage of the surface waves propagation. The final AiP design is shown in Figure 4 with respect to industrial design rule constraints.

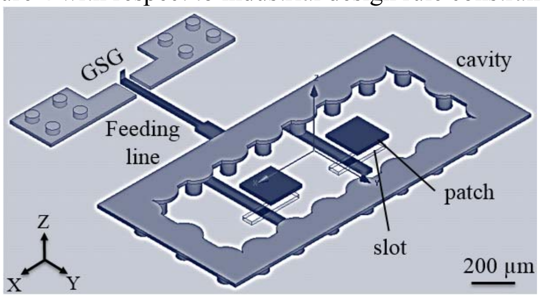

Fig. 4. HFSS 3D-view of the designed AiP.

The antenna simulations were performed with the HFSS full wave electromagnetic 3D solver. A simulated broadside realized gain of 8 dBi was achieved between 200 GHz and 280 GHz (33% relative BW) as shown in Figure 6. This AiP was fabricated using a standard semi-additive manufacturing process.

B. *Lens design*

A lens was co-designed to increase the AiP's gain. Thanks to its elliptic shape, the signal radiated by the AiP at the bottom of the lens is collimated thereby increasing the gain. This lens was fabricated with a Fused Deposition Modeling 3D printer. A standard ABS plastic was used for the lens dielectric material. This low-cost plastic, often used in additive manufacturing, features a tan(δ) of 0.008 at 60 GHz [5] and was successfully evaluated up to 140 GHz [6].

With a lens diameter of 9 mm, the AiP-lens system exhibits a simulated gain of 23 dBi throughout the 200-280 GHz band (Figure 6). The prototyped lens and AiP are shown in Figure 5.

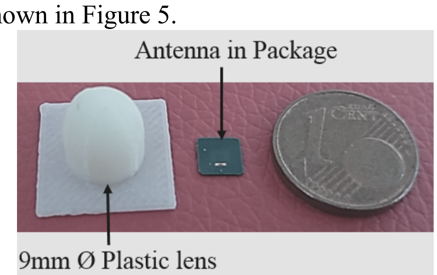

Fig. 5. Lens and AiP prototypes.

C. AiP-lens gain measurement

A probe-based measurement setup working between 200 GHz and 325 GHz was used for the evaluation of the antenna-system's gain. The measured broadside gain of the AiP and the AiP-lens system are shown in Figure 6. An obvious gain discrepancy is observed between the measured and simulated gains, with a notch located around 270 GHz. However, if considering the 20 GHz BW between 220 GHz and 240 GHz, gains of around 5.4 dBi and 17 dBi are still achieved for the AiP and AiP-lens system respectively (8.7% bandwidth).

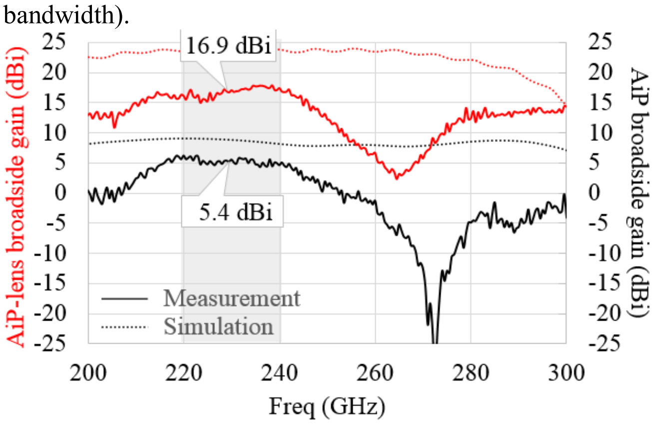

Fig. 6. Simulated and measured broadside gain for the AiP alone and with the co-designed dielectric lens.

This strong simulation/measurement difference is actually due to dimension errors within the fabricated AiP. This statement was verified through X-ray imaging of the AiP prototype. Therefore, if a better control of the semi-additive fabrication process is mastered, the broadside gain could be improved.

IV. Conclusion

Successful indoor wireless transmission with up to 10 Gb/s data transfer was achieved using an SiGe photodiode for the transmitter. Towards higher date rates transmission, future measurements will be undertaken in order to validate the photodiode's performance above 40 Gb/s.

An Antenna in Package associated with a 3D-printed lens was able to achieve 17 dBi broadside gain between 220 GHz and 240 GHz. Moreover, with a better fabrication process control, at least 20 dBi could be achieved throughout 200-280 GHz.

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