Integrated Pseudo-Lens Structures for On-Chip Antennas at 180 GHz

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Abstract—**Pseudo-lens structures for a fully integrated, stacked open-slot on-chip antenna design for the frequency range around 180 GHz are presented. Due to the use of the silicon substrate as pseudo-lens no reflector or external dielectric lens is required. The antenna is using the multi-layered IHP 130 nm SiGe BiCMOS technology (SG13).**

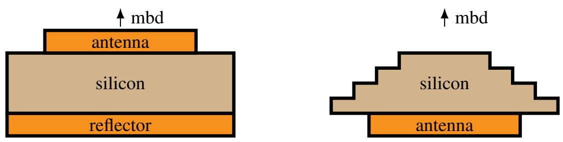
1. Introduction

Today there is a high demand for integrated on-chip antennas due to high requirements for the positioning of antenna and front-end in packaging technologies. This paper presents different pseudo-lens structures for an integrated, stacked open-slot on-chip antenna to enhance its radiation characteristic. Currently most solutions suffer from the silicon substrate beneath the antenna structure, due to the high relative permittivity the main part of the energy propagates inside the substrate. Therefore, a reflector or a dielectric lens is necessary in order to radiate the energy towards the desired direction. In the approach presented in this paper neither a reflector nor an external dielectric lens is required because the energy is directly radiating through the silicon substrate, which is used as pseudo-lens. Hence, limitations due to the reflector can be avoided and a higher bandwidth is expected. A comparison of the conventional and the novel approach is shown in Fig. 1.

IHP already manufactured the conventional design in their SG13 process [1]. The fabricated chip has a size of 1 mm^2. A detailed description of the design and all electrical properties is given in [2].

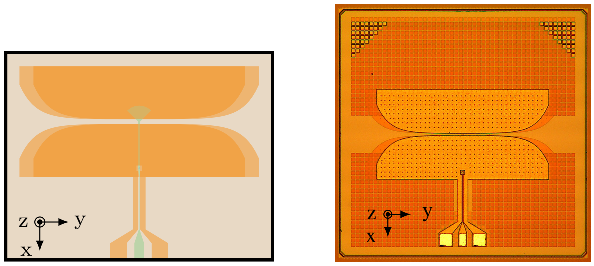
2. Pseudo-Lens Structures

All investigations regarding the pseudo-lenses are based on the open-slot antenna presented in [2]. Fig. 2a shows a scheme with the two antenna layers and the feeding line in between and Fig. 2b the chip-photo of this design. After



(a) with reflector (b) with pseudo-lens

Figure 1: Comparison of main beam direction (mbd) between conventional design with reflector and pseudo-lens structure. The reflector is added after manufacturing.



(a) Scheme (b) Chip-photo

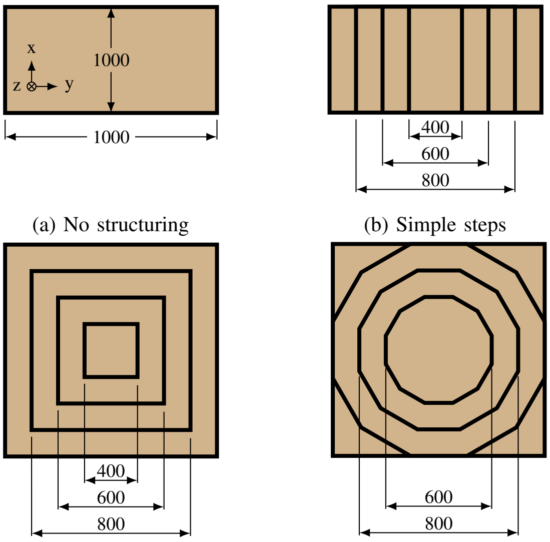
Figure 2: View from top with open-slot structures and cpw-feed.

manufacturing the silicon substrate has a height of 300 µm. There is no production-related metalization beneath the silicon, therefore the silicon substrate can be postprocessed to a pseudo-lens structure. The aim is to improve the radiation characteristics and the bandwidth in comparison to the design with reflector. Fig. 3 gives an overview of different investigated pseudo-lens structures. Fig. 3a represents the simplest case, the antenna has been flipped and the silicon substrate is not postprocessed. Therefore, the pseudo-lens has the shape of a cuboid. Another simple shape is a step structure like shown in Fig. 3b and Fig. 1b. The steps have a width of 100 µm and a height of 80 µm. An enhancement represent the pyramid-shaped and the conical pseudo-lens in Fig. 3c and Fig. 3d, respectively. In both designs the steps have the same height and width as mentioned above. For fabrication, it is intended to use a laser beam. For this procedure the antenna can be fixed in a glass mask, which has to be provided with markers for the positioning of the laser.

3. Simulation Results

In the first step only the radiation patterns are compared. Due to the fact that already manufactured on-chip antennas shall be used for the investigation of the pseudo-lenses, the return loss will change in any case. Therefore, only the gain was plotted in Fig. 4. If the measurements confirm the simulation results an optimized antenna design will be fabricated later on.

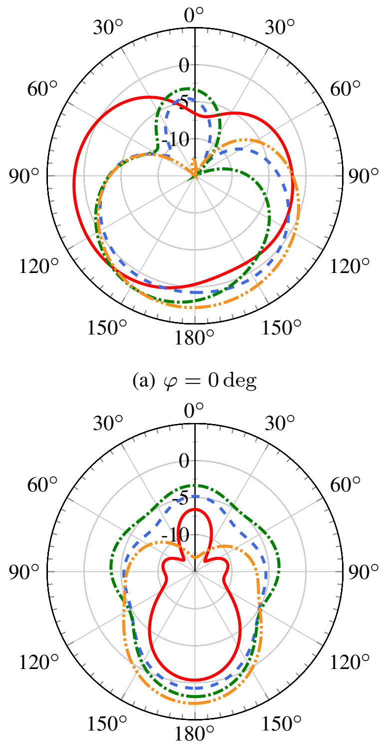
All simulations were conducted with HFSS 15. For the investigations a relative permittivity of $\varepsilon_r = 11.9$ and a conductivity of $\sigma = 0.02\,\mathrm{S\,m^{-1}}$ for the silicon substrate were assumed. A comparison of the radiation pattern at 180 GHz for different pseudo-lens structures is presented



(a) No structuring (b) Simple steps

(c) Pyramid (d) Cone

Figure 3: Bottom view of the antenna structure to the silicon substrate. Dimensions in micrometer, (a) and (b) not drawn to scale in x-axis



(a) $\varphi = 0\,\mathrm{deg}$

(b) $\varphi = 90\,\mathrm{deg}$

Figure 4: Comparison of the gain in dBi for different lens-structures at 180 GHz: no structuring, simple steps, pyramid, cone .

in Fig. 4. It can be seen that the radiation pattern of the non-postprocessed antenna without reflector (cf. Fig. 3a) is tilted in the $-x$-direction due the coplanar waveguide (cpw). Therefore, the gain in the main beam direction is about –0.5 dBi. Even if a relative simple shape like steps is used for the pseudo-lens (cf. Fig. 3b) the distortion due to the feeding line is clearly reduced. In this case the gain in main beam direction already rises to approx. 1 dBi. A more complex shape results in a further enhancement. The use of a pyramid yields to a gain of 2 dBi, with a cone 2.8 dBi were achieved. Another positive effect of the cone is the reduction of the back-lobe. Fig. 5 shows a comparison of the total gain over frequency for all designs. It is discernible that a pseudo-lens enhances the bandwidth as well as the gain. The bandwidth is defined as the frequency range, in which a total gain higher than 0 dBi is achieved. The design with reflector has a relative bandwidth of 17.7 % whereas the proposed conical pseudo-lens achieves 20.3 %. In addition, the gain rises over the whole frequency range, e. g. for 180 GHz an improvement of 1 dB is achieved. Concerning the return loss an impedance bandwidth of 25.6 % ($|S_{11}| < -10\,\mathrm{dB}$) is achieved for the most promising design with the conical pseudo-lens. This is also an enhancement in comparison to the conventional design with reflector, which is shown in [2]. Besides it has to be considered no optimizations regarding the open-slot antenna were done up to now for the pseudo-lens approach, therefore a further improvement is expected.

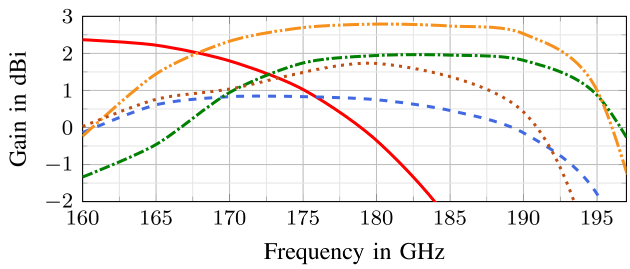


Figure 5: Gain vs. frequency in main beam direction for different lens-structures: no structuring, simple steps, pyramid, cone , with reflector

4. Conclusion

Different pseudo-lens structures for bandwidth and gain enhancement were presented. The proposed designs achieve a higher bandwidth as well as higher total gain in comparison to a conventional design with reflector. The manufacturing of the pseudo-lenses is currently in progress.

Acknowledgment

This work is supported by the German Research Foundation (DFG) in the project DAAB as part of the special priority program (SPP) 1655.

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