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DOI

[10.1109/IRMMW-THz.2019.8874265](https://doi.org/10.1109/IRMMW-THz.2019.8874265)

Publication date

2019

Document Version

Accepted author manuscript

Published in

IRMMW-THz 2019 - 44th International Conference on Infrared, Millimeter, and Terahertz Waves

Citation (APA)

Campo, M. A., Carluccio, G., Blanco, D., Bruni, S., Litschke, O., & Llombart, N. (2019). Dielectric-Grating In-Lens Polarizer for beyond 5G Communications. In *IRMMW-THz 2019 - 44th International Conference on Infrared, Millimeter, and Terahertz Waves* (Vol. 2019-September). Article 8874265 IEEE. <https://doi.org/10.1109/IRMMW-THz.2019.8874265>

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Dielectric-Grating In-Lens Polarizer for Beyond 5G Communications

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Abstract— A high-gain broadband leaky-wave fed lens antenna with an integrated dielectric gratings polarizer covering the whole G-band (140-220GHz) is presented. This work focuses on the polarizer gratings manufacturing and in particular on the selection of plastic materials and the fabrication process refinement. The polarizer geometry has been designed and optimized to be compatible with standard milling techniques. A quasi-analytical method based on an analysis of the lens antenna in reception is used to validate the in-lens polarizer performance. Several prototypes have been fabricated, finally obtaining an excellent match between measurements and quasi-analytical results.

I. INTRODUCTION AND CONCEPT

THE continuously growing demand for high speed communications requires the development of groundbreaking antenna and system approaches. The use of frequency bands above 100 GHz is currently one of the main research streams, as the availability of very large bandwidths at these higher frequencies represents a promising resource to provide high data rates, with low computational effort [1]. However, the wave propagation loss increases proportionally to the square of the frequency, and therefore moving to higher frequency bands requires the use of high gain antennas to fulfil the link budget. Besides, the available output power at the transmitter decreases for higher frequencies, which magnifies the importance of achieving highly efficient front-ends and antennas. The use of circularly polarized antennas in scenarios with moving terminal antennas is the key to avoid power loss due to polarization mismatch.

In this contribution, a low-loss, high-gain circularly polarized (CP) lens is presented (Fig. 1a). Based on the dielectric gratings concept [2], a broadband optimized polarizer has been designed to be integrated inside the lens. Both lens and polarizer are manufactured in plastic material (HDPE and Topas[®], with dielectric permittivity $\epsilon_r = 2.3$), enabling low-cost fabrication. The polarizer and lens are fed by the linearly polarized resonant Leaky Wave Antenna (LWA) presented in [3]. The LWA feeder radiates most of the energy below the dielectric-air critical angle, and hence avoids impinging on the polarizer beyond its critical angle.

The accurate low-cost fabrication of sub-wavelength dielectric corrugations at frequencies higher than 100GHz represents a challenge. In the following sections, the fabrication issues and the optimization of the manufacturing process are described. Different materials and milling tools have been investigated, arriving finally to a cost-effective approach with standard milling techniques.

II. POLARIZER GEOMETRY AND FABRICATION

One-dimensional (1D) pyramidal gratings are proposed in this work to be used as dielectric polarizer (Fig. 1c). This

shape improves the bandwidth and transmission with respect to the standard rectangular-grating used in [2], and enables the fabrication with standard milling techniques at frequencies higher than 100 GHz. 1D gratings in any dielectric material originate different effective ϵ_r for the electric fields polarized parallel and perpendicularly with respect to the 1D structure invariant direction. The polarizer exploits this effect to generate 90deg phase shift between two orthogonal polarized fields, creating circular polarization. In case of using plastic materials with $\epsilon_r \sim 2.5$ the effective anisotropy is low, and thus the resulting grating aspect ratio becomes very large, encumbering the fabrication. In this work, we propose reducing the grating aspect ratio by dividing the unit cell into four stacked pyramids with 1.3mm height and 500 μ m width. These can be fabricated in three layers, as shown in Fig. 1b and Fig. 1c. In the central layer, a dielectric slab of 2mm supports gratings on both sides. The pyramidal form provides a smooth transition between the dielectric and air characteristic impedances. In this way, alignment between the different layers is not needed to achieve a good transmission performance.

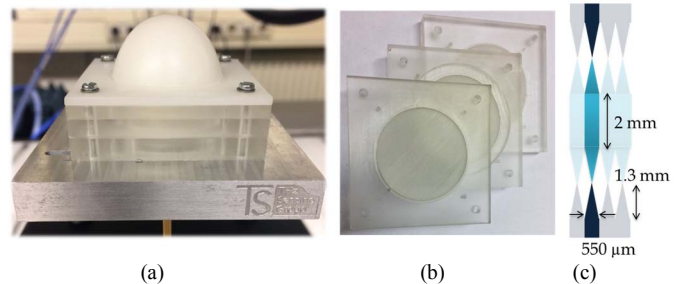


Fig. 1. a) Lens prototype with integrated polarizer (CP lens). b) Polarizer layers. c) Unit cell geometry. The different fabricated layers are shown in different shades of blue.

The milling tool used in the fabrication has a triangular longitudinal section, with the same angle as the pyramids, as shown in Fig. 2. The pyramid angle has been chosen as steep as possible to minimize the number of layers, while still being compatible with standard milling tools. Several materials and milling techniques were investigated in order to arrive to an optimized fabrication procedure for the described polarizer geometry. HDPE material, used in the lens fabrication due to its very low loss characteristic, was discarded after several trials, as it is too soft to be milled in this particular geometry. Topas[®] material was chosen as the second best candidate in terms of loss. In this case, a previous annealing process was needed to reduce the internal tension in the material and hence avoid internal cracks. A gear cutter was used to perform the first milling attempts on this material. This milling technique had provided good results in previous tests with materials such as PPMA, as shown in Fig. 2b. However, first trials with

Topas[®] showed high fragility in this dielectric, causing fractures all over the slab, and especially at the top of the pyramids. This can be appreciated in Fig. 2c. Eventually, a drilling tool was used to manufacture two prototypes with Topas[®], as shown in Fig. 2d (second prototype), performing a step-wise milling process to prevent fractures in the dielectric.

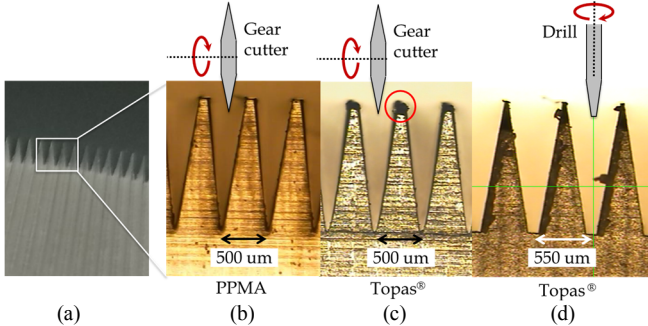


Fig. 2. a) Detail of a polarizer layer. (b) PPMA gratings milled with a gear cutter. (c) Topas[®] gratings milled with a gear cutter. (d) Final Topas[®] gratings milled with a pyramidal drill (second prototype).

While the gear cutter preserves a sharp edge, the tip of the drill tool loses its sharpness, ending up with a width of $\sim 100\mu\text{m}$. In this way, the final polarizer geometry in Topas[®] exhibits $\sim 100\mu\text{m}$ wide valleys between pyramids, as shown in Fig. 2d. In order to reach the expected pyramid height (see Fig. 3), it is crucial to take this fact into account when defining the periodic geometry. With this aim, the initial period of $500\mu\text{m}$ was increased to $550\mu\text{m}$. This modification has a negligible impact on the polarizer performance.

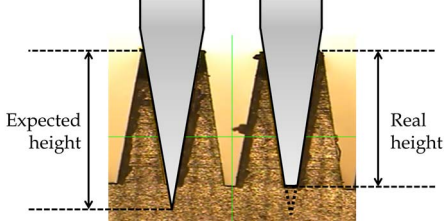


Fig. 3. Tools with same angle but different tip width (infinitely thin on the left, $100\mu\text{m}$ on the right). To reach the expected pyramid height with the tool on the right, the period (pitch between pyramids) should be increased.

III. PROTOTYPE DESIGN AND MEASUREMENTS

The CP lens has been optimized applying a quasi-analytical approach, considering the antenna in reception mode, as described in [4]. This method allows to perform a fast optimization of the lens aperture efficiency η_{ap} and lens axial ratio AR . The final results have been validated with FW simulations (with multiple reflections) with very good agreement. FW simulation results show $\eta_{ap} > 80\%$ and $AR < 3$ dB over 40% bandwidth.

In order to verify the proper functioning of the CP lens, two different coupling measurements were performed. In the first setup, a metallic reflector is placed on top of the CP antenna, as shown in Fig. 4a, and the power reflected at the antenna feed is measured. The LWA lens feeder field presents linear polarization (e.g. vertical), which is transformed in circular polarization after propagating along the polarizer (e.g. left handed). This CP wave impinges on the metal plate, is reflected with orthogonal CP (e.g. right handed). After

propagating back through the polarizer, it becomes linearly polarized (e.g. horizontal) orthogonal to the feed polarization. Consequently, no reflected wave is received when the polarizer performs a perfect conversion (at the center frequency, 180GHz). The expected coupling can be determined with the quasi-analytical approach in reception (see [4]), using the PO field reflected in the metal plate as incident wave impinging on the lens. Fig. 4a shows the quasi-analytical (including ohmic and dielectric loss) and measurement results. As the quasi-analytical evaluation considers only the first order rays, the measurements have been time gated to eliminate the effect of multiple reflections. Two polarizers were fabricated with Topas[®] using a drilling tool. The first prototype, with a period of $500\mu\text{m}$, did not take into account the $\sim 100\mu\text{m}$ wide valleys between pyramids. Therefore, pyramids reached only a height of 1.1mm. As a result, the minimum coupling was shifted up to 210GHz. For the second prototype, the period was increased to $550\mu\text{m}$ (Fig. 2d), resulting in a pyramid height of 1.3mm. Finally, the results were in agreement with the quasi-analytical results.

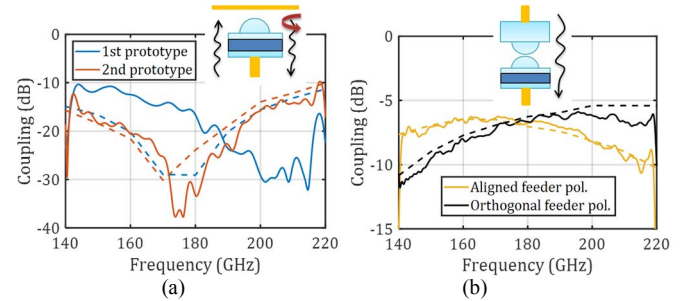


Fig. 4. a) Coupling in reflection with metallic reflector. b) Coupling in transmission with LP lens, for the second prototype. In both, solid line: measurements; dashed line: quasi-analytic results.

In a second measurement setup, the coupling between the CP lens and a linearly polarized lens (LP lens) was measured, as shown in Fig. 4b. Here, two measurements have been performed, where the polarizations in the CP and LP lens feeders (both linear) were aligned and orthogonal with respect to each other. This coupling can be as well calculated quasi-analytically, using as incident wave impinging on the CP lens the PO field from the LP lens, propagated until the plane between the two lenses. If the polarizer generates a perfect circularly polarized field, the same amount of power should be measured in both aligned and orthogonal arrangements. Fig. 4b shows the time gated measurements for the second fabricated prototype. Both coupling levels cross at 180GHz, in good agreement with the quasi-analytical results (including ohmic and dielectric loss in both lenses).

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