Development of Hybrid Multi-Phase Zone Plate Fresnel Lenses for Frequency of 585 GHz

Surya Revanth Ayyagari[1], Simonas Indrišiūnas[2], and Irmantas Kašalynas[1]

1 Terahertz Photonics Laboratory, Center for Physical Sciences and Technology (FTMC), Saulėtekio 3, 10257 Vilnius, Lithuania

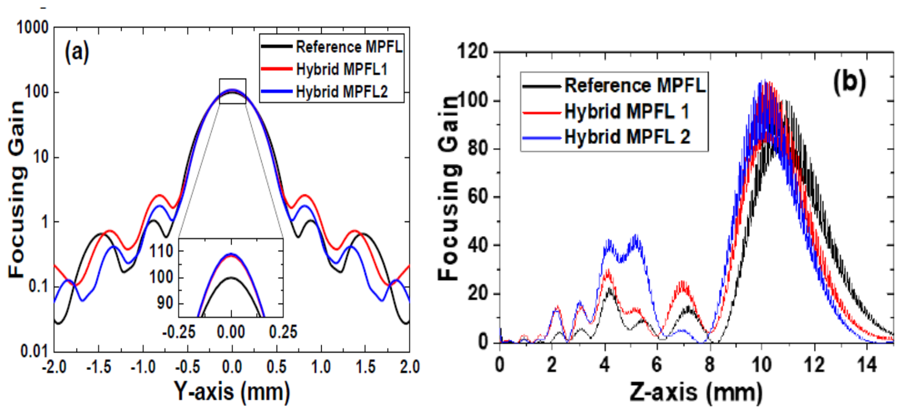
2 Laser Microfabrication Laboratory, Center for Physical Sciences and Technology (FTMC), Savanoriu ave. 231, LT-02300 Vilnius, Lithuania

Abstract The multi-phase zone plate Fresnel lenses (MPFLs) capable with optimized performance was developed on the semiconductor silicon (Si) wafer for operation at selected frequency in the THz range. The hybrid MPFL was numerically designed by simplifying a phase profile in the outer zones area and by thorough performance optimization allowing to reach the focusing gain values to be similar or even up to 10 % higher as in the standard design MPFL. Overall manufacturing complexity and time of such hybrid diffractive optical elements were significantly improved demonstrating both in theory and in experiment a very good quality of focused diffractive beams [1]

Numerical Development

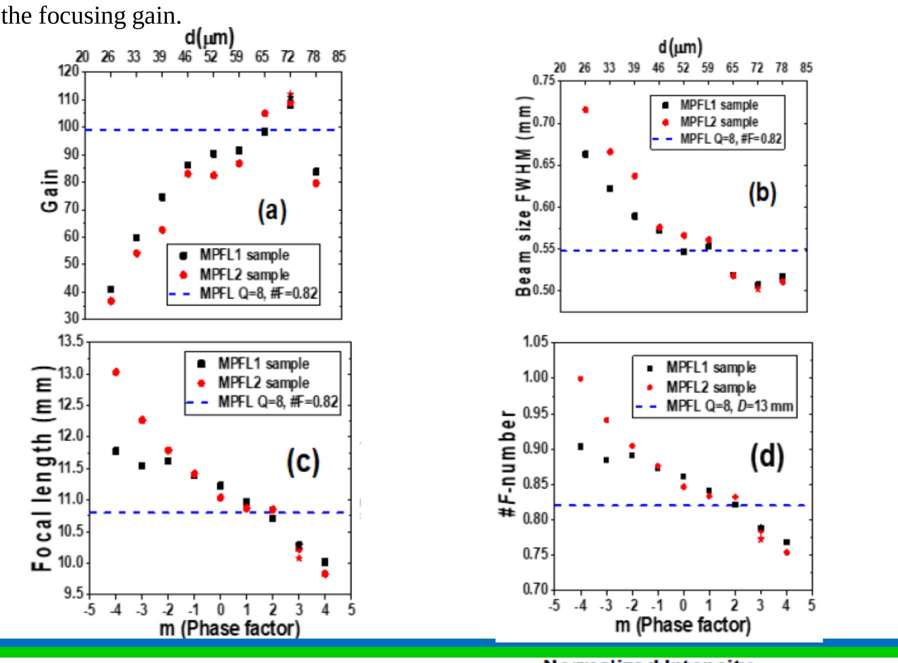
Parameters of a loss-free Si wafer with a thickness (h) of 0.5 mm was used to design the hybrid MPFL samples of different shape and step profiles. The reference MPFL was designed using the following equations[2]:

$$r_n = \sqrt{\frac{2\lambda n(F+\frac{d}{2})}{Q} + \frac{n^2\lambda^2}{Q^2}} \qquad d = \frac{\lambda}{Q(\varepsilon-1)} \qquad d = \frac{\lambda}{Q(\varepsilon-1)}\left(1+\frac{m}{8}\right),$$



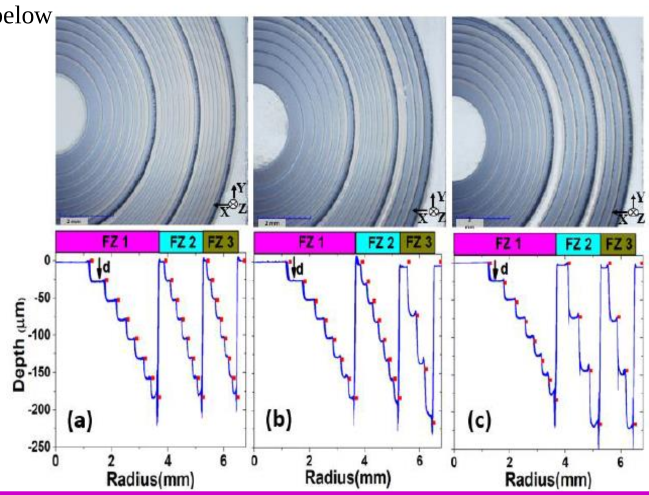
Modeling results

The phase shift for the optimized phase profile (hybrid MPFL) samples is chosen step by step modifying the depth of subzones with a factor of $(m/8)$ times the depth of subzone to the actual subzone depth, at outer Fresnel zones until the lens reaches maximum value of the focusing gain.



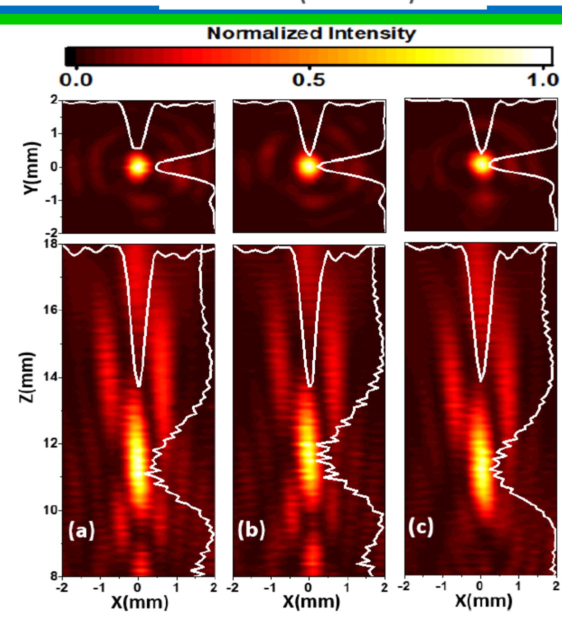
Fabrication Procedure

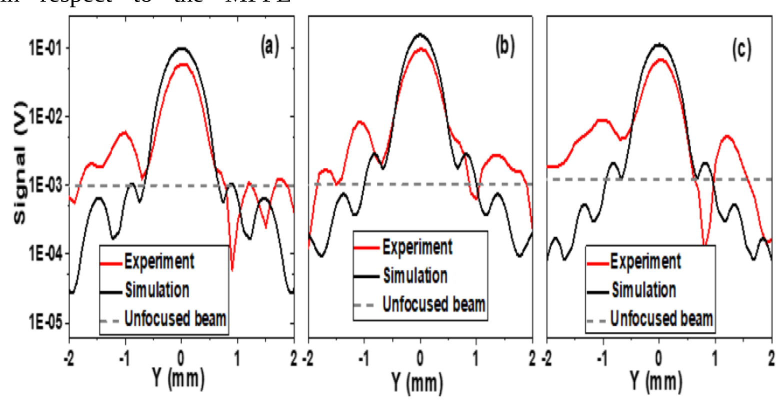
The zone plates were patterned by an industrial-scale pulsed laser (Atlantic 60, EKSPLA uab) with a pulse duration of 10 ps, operation wavelength of 1064 nm, scan speed of 856 mm/s (47% spot overlap), 32 μm laser spot size diameter, 11.8 J/cm2 laser irradiation fluence, hatch angle rotation of 45 deg after each scan and etch depth of 0.2 μm per layer which allowed to maintain precise control over the profile shape of the MPFLs. Pictures of the fabricated samples and their step profiles scanned from center towards edge side are shown below



Experimental Validation

Focusing performance of the samples was explored experimentally using a THz continuous wave system set to operate at the frequency of 585 GHz. The 585 GHz frequency radiation generated by Schottky diode-based AMC (Amplification Multiplication Chain) outcoupled via horn antenna was collimated using HDPE lens to measure the focusing performance of MPFL samples. The THz beam outgoing from the sample was evaluated with microbolometer detector which was placed on an automated 3D scanning stage system to measure the intensity distribution along the optical axis (Z-axis) and in the focal plane (X- and Y-directions) in respect to the MPFL sample.





Secondaments

UDE:M18 for ~1 months, for introduction to low-loss optical phase and TTD modulators.

ULIL: M24 for ~1.5 months, for diffractive optics integration with UTC-PD source

DAS Photonics: M30 for ~1,5 months, for testing devices in spectroscopic imagers

References

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[4] M. Rachon et al., "Enhanced Sub-wavelength Focusing by Double-Sided Lens with Phase Correction in THz Range," J. Infrared, Millimeter, Terahertz Waves, vol. 41, no. 6, pp. 685–696, Jun. 2020, doi: 10.1007/s10762-020-00696-0.

Presented by: Mr. Surya Revanth Ayyagari (ESR 9)
PhD student, Terahertz Photonics lab
Department of Optoelectronics
Center for Physical and Technology Sciences (FTMC)
Email Id: surya.revanth@ftmc.lt

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