3D-Printed THz Radiator for Pump-probe Experiments

Raziyeh Dadashi¹, Fahd Faridi², Rasmus Ischebeck³, Uwe Niedermayer², Frank Zimmermann⁴, Mike Seidel^{1,3}

¹ École polytechnique fédérale de Lausanne ² Technische Universität Darmstadt ³ Paul Scherrer Institut ⁴ CERN

Introduction

THz radiation with sufficient intensity finds various applications, including pump-probe experiments in freeelectron lasers, wireless communication, material analysis, and process control in biology, pharmacy, and medicine. The most common process for generating THz radiation is by optical rectification, in which laser pulses incident to a nonlinear crystal produce broadband THz pulses. A compact and cost-efficient alternative approach uses free electrons passed along a periodic structure, which emits synchronous radiation via the Smith-Purcell effect. The image below shows the chamber used for THz generation in SwissFEL.



Smith-Purcell Effect

This effect describes the electromagnetic radiation from a periodic structure excited by electron particles. The wavelength of Smith-Purcell radiation is 1

$$=\frac{a}{m}\left(\frac{1}{\beta}-\cos\theta\right)$$

Where θ is the radiation angle with respect to the electron beam, β is the normalized velocity of the electrons, a is the periodicity of the structure, and m is the mode order. The inverse designed structure below was experimentally tested in SwissFEL.²





Structure Design and Simulation

In this work, we designed and 3D-print a periodic conical shape structure out of PMMA (n = 1.628) to generate and guide the THz radiation. According to our simulation, the THz radiation improves by increasing the refractive index. The following is the analytical geometry calculation we did for the structure:

$$\alpha = \arcsin \frac{R}{L} = \arctan \frac{1}{\beta n}$$
$$\sin \kappa = \frac{\sqrt{R^2 + L^2}}{L_C}$$
$$L_T = L_C \cos \kappa = \sqrt{R^2 + L^2} \cot \kappa$$



Manufacturing

As shown above, the THz radiation improves by increasing the refractive index; therefore, we are exploring the use of mixture of quartz with PMMA resin to print the structure.



Measurements

In these plot and table below several important properties of two cylinders with different heights (5mm and 10mm) were measured for structures out of PMMA and PMMA with quartz. The powder does not only increase the refractive index, but also reduce the absorption. However, the absorption is still high.

Material	Refractive Index for 0.5 THz
PMMA	1.628



PMMA+quartz	1.81
Quartz	≈ 2.14



To Do ...

- Using PMMA with Zirconia powder to print the structure
- Improve the distribution uniformity of grains in the structure
- Optimize the structure
- Taking into account manufacturing tolerances
- Beam tests in SwissFEL

References

- 1. Smith, S. J.; Purcell, E. M. Visible light from localized surface charges moving across a grating. Phys. Rev. 1953, 92, 1069-1069.
- 2. Hermann, B,: et al. Inverse-Designed Narrowband THz Radiator for Ultrarelativistic Electrons, ACS Photonics 2022, 9, 4, 1143–1149.

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