Highly efficient beam shaping optics for compact THz imager

Roman Kleindienst, Sebastian Stoebenau, Stefan Sinzinger
Technische Universität Ilmenau, Fachgebiet Technische Optik, Institut für Mikro- and Nanotechnologien
roman.kleindienst@tu-ilmenau.de

Lothar Moeller
Bell Laboratories, Alcatel-Lucent, 791 Holmdel-Keyport Rd, Holmdel, NJ 07733, USA
lmoeller@alcatel-lucent.com

We describe an efficient and compact THz illumination system and its fabrication technologies. The illumination system is part of a THz imager that can be used for detecting concealed weapons.

1 Introduction

Progress in the development of miniaturized THz-sources with sufficient output power as well as uncooled 2-dimensional detector arrays for the frequency band < 1 THz open up a wide field of applications. In combination with efficient optical elements they enable compact THz imagers with real time image acquisition for security applications [1].

Illuminators are essential parts for active THz imaging systems and consist of a source and a beam shaper to efficiently distribute the source power across the FOV and evenly light the object plane. Significant R&D has been spent on designs for 'Gaussian-to-tophat beam shapers' (GTBS) [2] with applications in the visible and THz range [3]. Here we report on the first refractive operating THz GTBS.

A large variety of cloth materials cause only small attenuation of T-rays at frequencies < 1THz where the reflection characteristics of human skin and weapon materials differ significantly [4], thus concealed weapons can be displayed at high image contrast. We choose as T-ray frequency 625 GHz to keep atmospheric absorption relatively small. This also allows for sufficiently high spatial resolution at acceptable imager apertures to distinguish commonly carried items (pencils, cell phones) from weapons such as knifes and hand guns at 3 m - 10 m standoff distances.

2 THz source and detector technology

A commercially available THz source, based on a frequency multiplier chain, emits 84 % of the output power (~1 mW) into the fundamental Gaussian mode [5] with a 1/e² half divergence angle of about 5°. Tuning the input synthesizer adjusts the THz frequency between ~ 600 to 640 GHz, though impedance mismatches of multipliers cause a non flat frequency response. In our experiment the T-ray beam is detected in the object plane with either a micro bolometer (effective pixel size of ~ 600 x 600 µm²), a Shottky diode coupled to a horn antenna, or a Golay cell. Computerized X-Y translation stages carry the detector, enabling automatic scanning of 2D fields. Lock-in amplifiers are applied to discriminate background noise.

3 Refractive Gaussian to Tophat Beam Shaper

The homogenous object illumination across an area of 0.18 m diameter (size of hand gun) at 3 m and 0.6 m (cross section of a person) at 10 m was simulated for refractive and diffractive GTBSs. While thin diffractive elements show lower absorption (polypropylene, n = 1.506 +0.00113 j @ 625 GHz), refractive GTBS can be manufactured with less fabrication errors and allow for applying an additional anti reflection structure [6]. This results in a better overall efficiency for refractive elements although their absorption losses are higher.

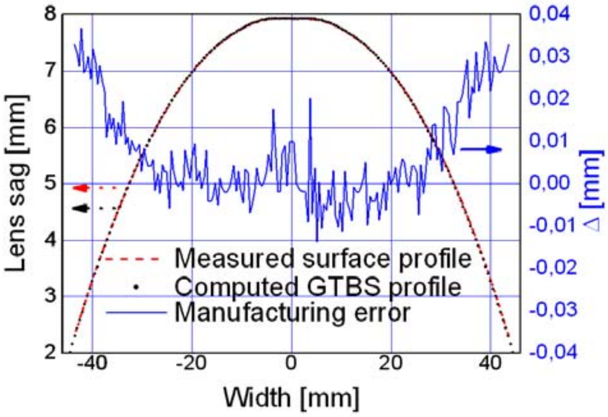

Fig. 1 *Design (black dots) and measured (red dashed line) profile of the GTBS, deviation of measured profile from computed shape (blue line).*

The beam transformation is performed by collimating the Gaussian beam followed by a beam shaping function. To minimize the absorption and Fresnel losses, both functions are combined in a single element possessing a refractive profile (black dotted line in fig.1) that was calculated by using a geometric starting phase. Afterwards the phase function was optimized by applying an IFTA algorithm considering the measured beam profile of the

THz source and the absorption profile of the resulting refractive profile in polypropylene.

We manufactured the GTBS by milling using a 6 mm cherry tool that has been moved helically over the polypropylene substrate. The resulting element with an effective diameter of 120 mm is shown in fig.2. A profile analysis of the GTBS surface (red dashed line in fig.1) with an optical profilometer showed a peak to valley deviation from the calculated profile of about λ/10 (blue line fig.1) and a Ra roughness of about λ/100.

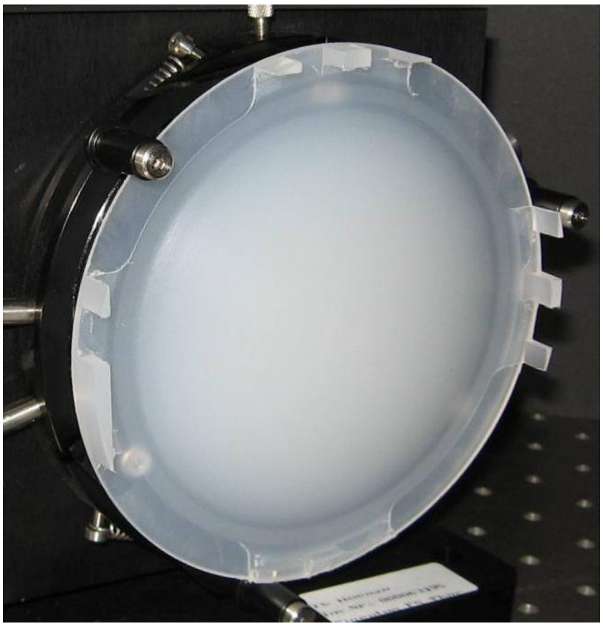

Fig. 2 *Gaussian to tophat beam shaper in polypropylene*

With the measured GTBS profile and the recorded input intensity profile we have simulated the illumination at 3 m and 10 m. For both illumination ranges an inhomogeneity of less than 10 % and an efficiency of ~92 % within the 90 % borders (not considering Fresnel losses) were calculated and considered acceptable for the application

Fresnel reflection induced efficiency losses and standing waves within the system, which would impair a homogenous intensity profile due to interference, can be minimized by structuring the surfaces with a sub-wavelength antireflection structure or a so called zero-order grating [7]. For T-rays these structures can be produced by micro milling and advantageously for low cost manufacturing be moulded in polymers. For our application we need a nearly polarisation independent structure in polypropylene with a transmittance of more than 99 % for an incidence of +/- 15° operating at 625 GHz. The design process based on RCWA simulations, considering fabrication restrictions like the cutting tool diameter plus its shape and the maximum cutting depth have resulted in a binary grating with period of 168 µm, a groove depth of 94 µm and a groove width of 89 µm. The simulations of the grating have shown a very low dependency on the state of polarization and a transmission of more than 99.45 % over the specified range of the incidence angles. A KUGLER Microgantry® nano4X ultra precision micro milling machine was used to fabricate a test structure in polypropylene with a groove width of 89 µm. Based on the experience of former manufactured optical components a depth deviation of less than 1 µm is to be expected [8] for the final structure.

4 Conclusion

Our concept for a compact and low cost GTBS provides homogenous illumination across the object plane of a THz imager. We have designed a GTBS by applying algorithms based on rigorous theory and scalar computational techniques considering technology restrictions and fabrication errors (technology-adapted design algorithms). Fabricated elements have been presented. With measured device parameters we have simulated alignment tolerances for the currently performed experimental characterization of the GTBS.

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