4 and 8-pixel THz Fourier phase gratings

B. Mirzaei[1,*], J. R. G. Silva[2], Y. C. Luo[1], X. X. Liu[3], L. Wei[4], D. J. Hayton[2], J. R. Gao[1,2], and C. Groppi[5]
[1]*Kavli Institute of NanoScience, Delft University of Technology, Delft, the Netherlands*
[2]*SRON Netherlands Institute for Space Research, Groningen/Utrecht, the Netherlands*
[3]*Microelectronics Department, Delft University of Technology, Delft, the Netherlands*
[4]*Imaging Physics Department, Delft University of Technology, Delft, the Netherlands*
[5]*School of Earth and Space Exploration, Arizona State University, AZ, USA*
[*]Contact: b.mirzaei@tudelft.nl

Abstract— Modelling, manufacturing and characterization of two 4 and 8-pixel Fourier phase gratings operated at 1.4 THz are reported, mainly applicable as local oscillator multiplexers for heterodyne receivers. Comparing the measurements with full 3D simulations shows good agreements and provides good understanding. Power efficiency of around 70% is experimentally derived for both gratings. We demonstrate the application of both, as multiple beam local oscillators to simultaneously pump (or operate) an array of 4-pixel superconducting mixers.

INTRODUCTION

Since terahertz heterodyne receivers are approaching quantum-noise limited sensitivity [1], to further improve spatial observing efficiency, multi-pixel heterodyne receivers [2] are necessary, which improve the mapping speed of the telescope significantly. Considering the challenges in providing suitable THz sources and complexities to synchronize the phase of many individual sources, generating multiple beams from a single source e.g. by a Fourier phase grating is more favorable.

Besides this primarily application in THz frequencies, phase gratings can be implemented in various fields, including imaging, coherent communication and optical computing.

Although several milestones have been reached towards developing THz phase gratings, little work can be found, beyond 1 THz.

In this work we present two phase gratings of 4 and 8-pixels, designed to operate at 1.4 THz by employing 13 Fourier coefficients. The designed surface structures, shown in Fig. 1(a,b), were manufactured on aluminum plates as shown in Fig. 1(c), by a computer numerical control (CNC) micro-milling machine.

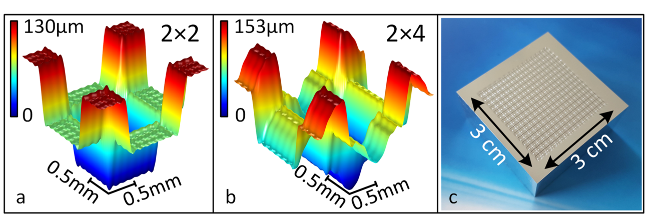

Fig. 1 3D surface profiles of unit cells of 4 (a) and 8-pixel (b) gratings with exaggerated z axis and a photograph of the manufactured 8-pixel grating (c).

MEASUREMENTS AND SIMULATION RESULTS

For grating's characterization, a high power 1.4 THz FIR gas laser in a proper setup is used. Despite small differences between the designed and fabricated gratings, we measured power efficiencies of both gratings to be around 70%, which is in a good agreement with the simulated values based on the ideal design. Fig. 2 shows the 3D simulated diffraction orders of the 8-pixel grating (a), and the good agreement between the simulated and measured diffracted beam pattern size and spatial distribution (b).

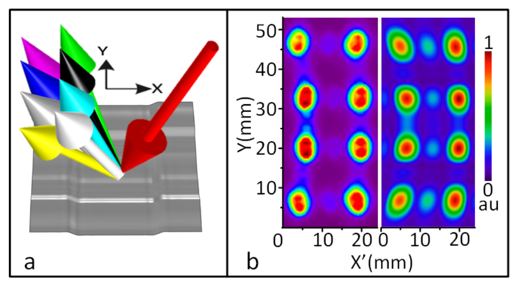

Fig. 2 a) Arrow schematics of the desired diffraction orders of the 8-pixel grating, calculated by 3D simulations, b) measured (left) and simulated (right) diffraction beam pattern of the 8-pixel grating.

Motivated by such results, we evaluate the real manufactured structure using full 3D simulation in COMSOL, where we find for the first time that, even with non-ideal machining, one can reach nearly the theoretically predicted efficiency and beam pattern. Moreover we find that by decreasing the number of Fourier coefficients from 13 to 6 in design, the efficiency drops about 4% while the minimum radius of curvature of the surface gets 4 times larger which ease the manufacturing by the same scale. These findings have a high impact on the manufacturability of a grating, making its fabrication less critical.

We also study the effect of the incident angle on the grating performance, where we find that by changing from 15° to 30° in four steps, the power distribution among diffraction orders becomes less uniform whilst the power efficiency decreases negligibly by less than 2%.

ARRAY DEMONSTRATION

We implement both gratings in a heterodyne experiment, for which we have built a 2x2 HEB array, using antenna coupled, quasi-optical NbN HEB mixers. We apply the 4-pixel grating together with the 1.4 THz gas laser to optically pump the array. Since we have no 8-pixel mixer array available, we examine the 8-pixel grating using the same source by coupling three groups of four left, four centre or four right beams. For all these configurations, we succeeded in fully pumping all the mixers and bring their current-voltage (IV) curves from superconductive to resistive state. Fig. 3 shows the results for the 4-pixel grating.

Applying the isothermal technique [3] to estimate the beam power at the detector and having estimated all the losses in the optical path from the laser to the mixer array and also taking the efficiency of the grating into account, we end up with about 25 μW for the total required input power, and about 50 μW for an 8-pixel mixer array. This order of power is reachable at lower frequencies (< 2 THz) by multiplier based solid state sources [4] and at higher frequencies by quantum cascade lasers [5].

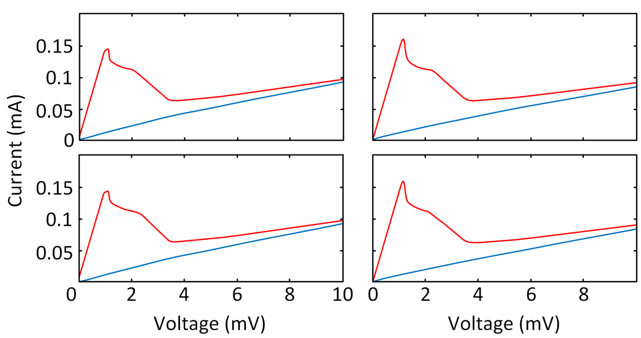

Fig. 3 I-V curves of the HEB array in superconductive (red) state with no incoming radiation, and resistive state (blue) when they are fully pumped by the grating diffracted beams.

This experiment establishes the fact that the grating is an extremely promising technology for generating a multiple beam local oscillator at the supra-THz, required for future astronomic observatories, such as NASA Galactic-extragalactic ultra-long-duration spectroscopic stratospheric observatory (GUSTO).

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