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Terahertz imaging with 45 pixels through spectral encoding of the k-space

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Imaging at terahertz frequencies (0.1-10 THz, wavelengths of 3 mm-30 μm) has received considerable attention thanks to the prospect of numerous imaging applications benefiting from the fact that many materials are semi-transparent to THz waves [1]. Today, one of the limiting facto is the acquisition time of a THz image. Due to the complexity of building highly sensitive THz multipixel arrays, single-pixel imaging using advanced processing techniques such as Compressive sensing has emerged as a viable tool to reduce the total acquisition time, since an image with *N* pixels can be reconstructed with *M*<*N* measurements [2]. In this work [3], we use the k-space/frequency duality to encode an image in the spectrum. We demonstrate experimentally for amplitude and phase masks than an image can be reconstructed with tens of pixels.

Our reconstruction algorithm uses the Fourier optics in a 2*f* system (1 lens) to encode the *k*-space components into the spectrum. A simple lens perform the spatial Fourier transform of the object. The spatial frequencies are $k_\xi = \xi\nu/cF$ and $k_\eta = \eta\nu/cF$, with F the focal length of the lens and (ξ, η) the spatial coordinates in the Fourier plane. Since the *k*-space components are proportional to the frequency ν, one can fix the detector at position (ξ_0, η_0) and record a linear segment of the *k*-space using a broadband spectrum: $k_\eta = (\eta_0/\xi_0) \cdot k_\xi$. By changing the ratio η_0/ξ_0, the whole *k*-space can be sampled. The simplest way to change this ratio is to measure along a circle of fixed radius ρ_0 in the (ξ, η) plane. Therefore, instead of performing a time-consuming 2D raster-scan, we can instead scan only along a single 1D circular path and use the broadband spectrum to scan along the radial coordinate. We demonstrate the reconstruction in two important cases: 1) Binary amplitude masks with object defined as $S(x, y, \nu) = S(x, y)E(\nu)$ and 2) phase masks with $S(x, y, \nu) = S(x, y)E(\nu)\exp[j2\pi\nu(\Delta_0 - \mu(x, y)/c)]$.

In Fig. 1(a-c), we present the reconstruction of a binary metal mask representing a maple leaf. In Fig. 1(a-b), we show the amplitude and phase of the *k*-space acquired using the broadband spectrum and a circular measurement path. The reconstructed object using the inverse transform we developed in [3] is presented in Fig. 1(c) with only 45 points along the circle. In Fig. 1(d-f), we imaged a 3D printed polymer phase mask with a subwavelength π engraving of 100 μm. In Fig. 1(e), we show the imaginary part of the the reconstructed object. With an additional reconstruction using a flat polymer plate, we can reconstruct the height of the engraving (Fig. 1(f)).

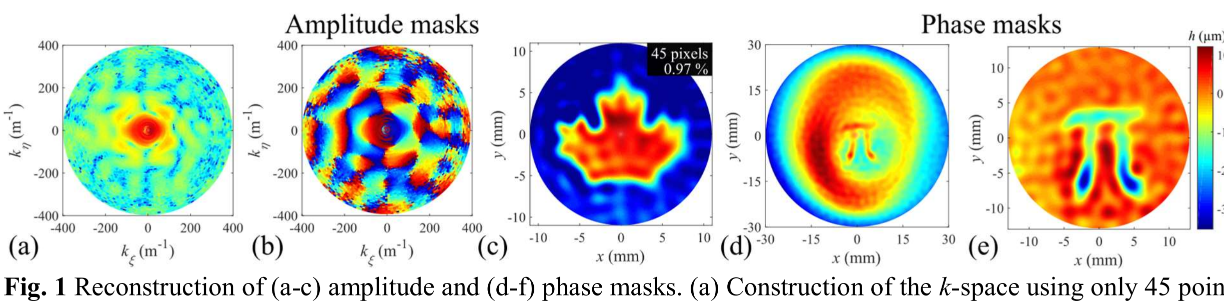

Fig. 1 Reconstruction of (a-c) amplitude and (d-f) phase masks. (a) Construction of the *k*-space using only 45 points: amplitude and (b) phase. (c) Reconstruction. (d) Imaginary part of the engraved phase mask and (j) measured height.

References

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[3] H. Guerboukha, K. Nallappan, and M. Skorobogatiy, "Exploiting k-space/frequency duality toward real-time terahertz imaging," *Optica*, **5**, 2018.