Analytical technique for subwavelength far field imaging

Viktor A. Podolskiy1,3,*, Sukosin Thongrattanasiri1, Nicholas Kuhta1, Anthony J. Hoffman2, Matthew Escarra2, Claire F. Gmachl3

1Department of Physics, Oregon State University, 301 Weniger Hall, Corvallis, OR 97331, USA
2Department of Electrical Engineering, Princeton University, Engineering Quadrangle, Olden Street, Princeton, NJ 08544, USA
3Department of Physics and Applied Physics, University of Massachusetts Lowell, One University Avenue, Lowell, MA 01854, USA
*viktor_podolskiy@uml.edu

Abstract: We develop a computational technique for imaging with subwavelength resolution based on far-field intensity measurements.

High-resolution imaging is of interest for a broad class of applications spanning all parts of the electromagnetic spectrum. Unfortunately, conventional far-field imaging is fundamentally limited by the free-space wavelength. The diffraction limit can be halved with structured illumination microscopy where the spectrum of the incident light is effectively doubled via interference [1]. Alternatively, in the far-field superlens, part of the evanescent radiation emitted by an object is resonantly enhanced via surface plasmon polaritons, and is subsequently converted into propagating waves with a subwavelength diffraction grating [2]. Both techniques rely on multiple measurements and numerical reconstruction algorithms to perform imaging of an unknown object and achieve \( \lambda_0/4 \) resolution. Here we present an approach capable of non-resonant imaging with resolution on the order of \( \lambda_0/20 \) with far-field measurements [3].

The fundamental difference between the diffraction-limited and subwavelength images is seen in wavevector space. The spectrum of a subwavelength focal spot is dominated by high-wavenumber components that exponentially decay away from the focal spot. The grating, that plays the role of image-reconstructing structure, located at the image plane, and translates the spectrum of the source according to

\[
k' = k_0 + mk_A,
\]

where \( k_0 \leq \omega/c = 2\pi/\lambda_0 \) is the incident field wavevector, \( m \) is the diffraction order, \( k_A = 2\pi/\Lambda \) is the grating wavevector, \( \Lambda \) is the grating period, and \( k' \) is the diffracted wavevector. Note that diffraction gratings can convert the originally evanescent information into propagating waves which can be measured in the far field. Provided that the far-field measurements of the same object are performed for different values of incident angle (different values of \( k_0 \)), the contributions of different diffraction orders to the final intensity distribution can be separated from each other, and the original field distribution can be calculated. Typical examples of the restored intensity distribution of subwavelength objects are shown in Fig. 1.

This work has been partially supported by ONR (grant #N00014-07-1-0457), NSF (grant #ECCS-0724763), and AFOSR (grant #FA9550-09-1-0029).

References