90nm resolution reconstruction from a polychromatic signal using monochromatic phase retrieval techniques

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The use of short wavelength sources for microscopy increases resolution via the diffraction limit, and allows the variation in optical contrast, such as that between carbon and water in the 2-4 nm regime, to facilitate useful imaging. However, high material absorption and consequent low phase shift, at such wavelengths limit the availability of focussing optics. For coherent illumination, the electric field just after an object can be reconstructed from its far field diffraction pattern by the process of Coherent Diffractive Imaging (CDI), which solves the well-known phase retrieval problem by iteratively applying constraints in the object and far field (Fourier) planes. Synchrotron sources have achieved 3 nm resolution using this technique [1].

Laboratory-based, laser-driven, high harmonic sources produce spatially-coherent radiation suitable for CDI. However, their broad frequency comb-like spectrum results in a diffraction pattern at the detector which is an incoherent sum of wavelength dependent diffraction patterns. Monochromating such sources has achieved 70 nm resolution via CDI [2], but results in a reduction in usable flux; a problem when the lower efficiencies of water-window generation are considered. Recently 100 nm resolution was achieved from polychromatic illumination using a modified Hybrid Input-Output (HIO) algorithm [3]. Such algorithms have a slow convergence due to their weaker constraints and require as much a priori knowledge of the sample as possible.

The high harmonic source used in this work generates extreme UV harmonics of the laser fundamental, using high peak intensity (10^{14} W cm^{-2}), 40 fs infrared laser pulses. A Mo/Si multilayer focussing mirror selects 3 main harmonics with 1.8% relative bandwidth, centred about the 29th (27 nm), and focuses them to a spot of 20 µm. The relative bandwidth of the spectral envelope is 13%. By recording a polychromatic diffraction pattern of a 2 µm binary object (figure 1b) illuminated with this source, we have achieved a diffraction-limited reconstruction with spatial frequencies corresponding to 90 nm detail (figure 1a) using a monochromatic HIO algorithm, unmodified except for the standard shrinkwrap [4] addition. The algorithm was applied in a series of generations, where the reconstruction from the previous generation with the lowest Fourier error was used to produce a set of solutions for the next generation, by applying a number of random phase distributions. Three generations were required to converge on the solution provided in figure 1a.

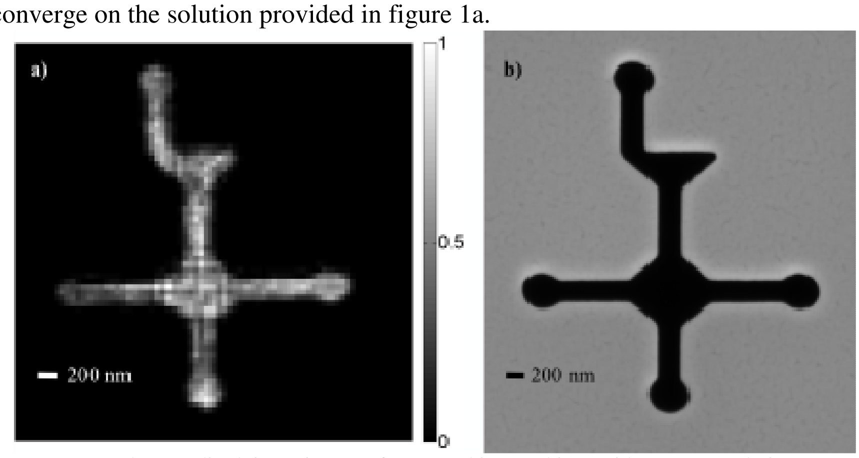

Fig. 1 Reconstructed normalised intensity a) of a 2um binary object with 90nm resolution reconstructed using a monochromatic algorithm from a polychromatic signal. b) An SEM image of the same object.

We believe that this result represents the limit of monochromatic algorithms, but that such solutions present an improved constraint for secondary algorithms, such as those described in [3]. This represents an important development in the progression to utilising the high relative bandwidth harmonics in the 2-4 nm regime.

References

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