Supporting Online Material for

Far-Field Optical Hyperlens Magnifying Sub-Diffraction-Limited Objects
Zhaowei Liu, Hyesog Lee, Yi Xiong, Cheng Sun, Xiang Zhang*

*To whom correspondence should be addressed. E-mail: xiang@berkeley.edu

Published 23 March 2007, Science 315, 1686 (2007)
DOI: 10.1126/science.1137368

This PDF file includes:
Materials and Methods
Fig. S1
References
Supporting Online Material

Optical Hyperlens Magnifying Sub-diffraction-limited Objects

Zhaowei Liu⁺, Hyesog Lee⁺, Yi Xiong, Cheng Sun and Xiang Zhang*

5130 Etcheverry Hall, NSF Nano-scale Science and Engineering Center (NSEC),
University of California, Berkeley, CA 94720-1740

⁺ Contribute equally to this work
*To whom correspondence should be addressed. E-mail: xiang@berkeley.edu

Materials and Methods

Sample fabrication and characterization

The optical hyperlens was fabricated by depositing alternating Ag and Al₂O₃ thin layers onto half-cylindrical cavity made in Quartz substrate. The fabrication of the quartz mold started with a 150 nm Cr film deposited on a flat quartz substrate using E-beam evaporation machine (EB3, BOC Edwards). Then a 50 nm open slit was inscribed on the metal film using a Focused Ion Beam system (FIB, Strata 201XP, FEI). Using Cr film as the etch mask, the half-cylindrical cavity was obtained by an isotropic wet etching of quartz in buffered oxide etch of 10:1 ratio. Adjusting the etching time allows precise control of the diameter of the half-cylindrical mold. Cr etch mask was finally removed by wet etching step using CR-7 Cr etchant. The cylindrical shape of the cavity is confirmed by Atomic Force Microscope (Dimension 3100, Veeco) measurement. The surface roughness is about 1.3 nm RMS.

The fabrication process was followed by depositing 8 pairs of Ag (35 nm)/Al₂O₃ (35 nm) thin layers onto half-cylindrical quartz mold, yielding hyperlens with inner cavity of 950 nm wide. Sub-diffraction-limited objects were inscribed into a 50 nm thick Cr layer at the inner surface by using FIB. Thin films were deposited using the same E-beam evaporator at vacuum level of 3×10⁻⁶ Torr. The film growth rate for Ag, Al₂O₃ and Cr was 2 nm/s, 0.25 nm/s, and 2 nm/s, respectively. The surface roughness of the inner surface of hyperlens is 1.7 nm RMS.

Material properties and numerical simulation

The cross-sectional view of the field distribution in Fig. 1a was simulated by COMSOL Multiphysics™ 3.3. The material permittivities used in the simulation are 2.174 for quartz [1] 3.217 for Al₂O₃ [2] and -2.4012+0.2488i for Ag [3]. These data are obtained by numerical interpolation of experimental data published in the references at the wavelength of 365 nm. The permittivity of Cr we used is -8.5490+8.9607i which is directly taken from reference [4]. The maximum mesh size of air and quartz substrate is 10 nm, while the maximum mesh size of the Cr layer and Ag/Al₂O₃ layers is 5 nm.
**Optical measurement method**

The sample was measured using optical microscope (Axiovert mat 200, 100X oil immersion objective, N.A. =1.4, Zeiss). The object was illuminated using mercury lamp (HBO, Zeiss). A band pass filter (center wavelength of 365 nm and bandwidth of 10 nm) and a UV polarizer were placed in the illumination light path to control the illumination condition. Magnified image was then captured using a UV sensitive TE-cooled CCD camera (VersArray 1300F, Princeton Instruments). To minimize the possible focusing error that could affect the image resolution, set of images taken at different Z-focusing position are collected. The Z-focusing was driven by a step motor (VEXTRA RK series 5-phase stepping motor) with fine scanning step of 50 nm. The images with the highest contrast are chosen to present in the manuscript for both hyperlens and the control experiments. Using a nanoscale line pair as an object (Fig. S1 A), the hyperlens image clearly shows the sub-diffraction-limited resolution of 130 nm (Fig. S1 B) and imaging resolution could be further improved by using high N.A. illumination.

![Fig. S1](image)

**Fig. S1** Hyperlens image of line pair object with line width of 35nm and spacing of 130nm. A, SEM image, B, hyperlens magnified image. The hyperlens is made of 16 layers of Ag/Al$_2$O$_3$.

**Reference:**