Supplementary Information for Bethe-hole polarization analyzer for the magnetic vector of light

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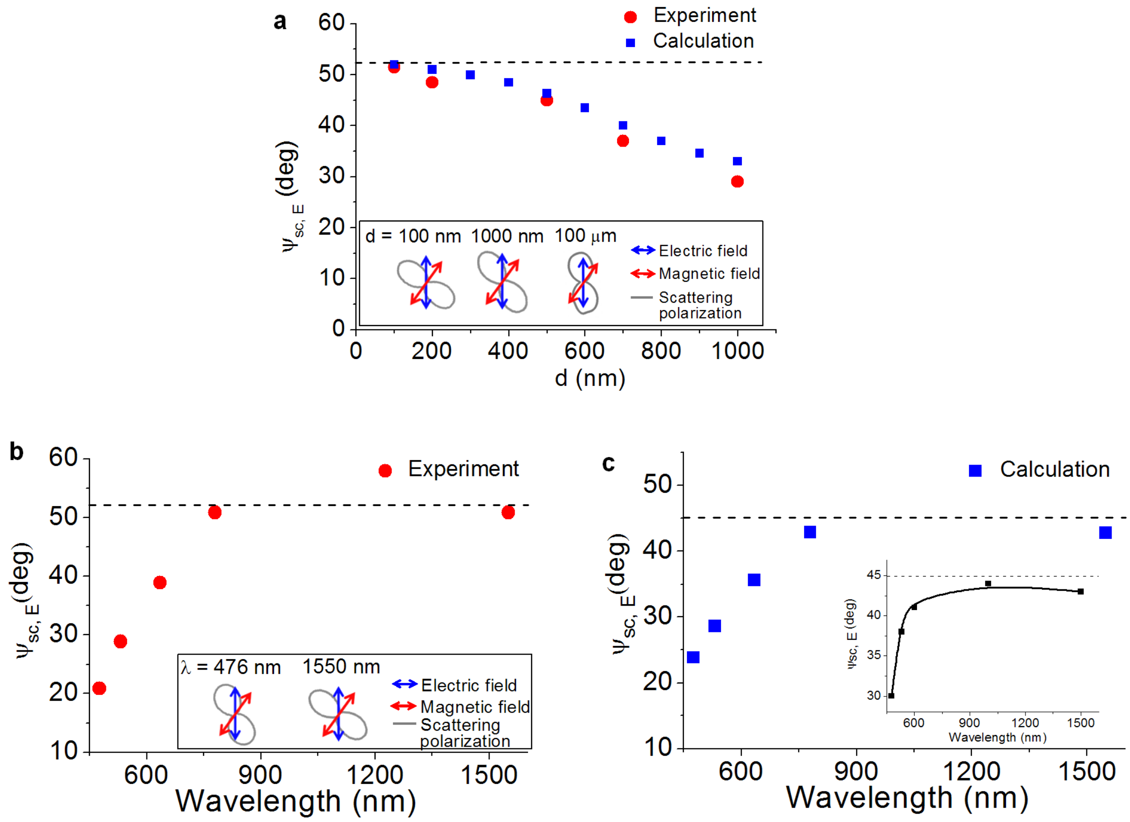

Supplementary Figure S1. a, Scattering field polarizations for various hole diameters (θ = 70°, λ = 780 nm). FDTD calculation (blue rectangle) and experimental (red circle) $\psi_{sc,\,E}$ for various hole diameters when ψ is fixed at 142°. The black dotted line, $\psi_{sc,\,E} = 52^{\circ}$, denotes the perfect magnetic polarizer case. The inset shows the polarization analyzed scattering intensities together with $\vec{\mathbf{H}}_t$ and $\vec{\mathbf{E}}_t$ for d=100 nm, 1000 nm, and 100 μm. **b,** $\psi_{sc,\,E}$ vs. wavelength for an 80 nm hole punctured on 80 nm-thick gold on a sapphire substrate (θ = 70°, ϕ=45°; ψ =142°). The inset compares the scattering polarization polar plots for 476 nm and 1550 nm wavelengths. **c,** FDTD calculation (blue rectangle) of $\psi_{sc,\,E}$ when ψ is fixed at 135° using realistic gold and sapphire dielectric constants. (Inset) FDTD calculation (black rectangle) of $\psi_{sc,\,E}$ when the size of hole is scaled with the wavelength keeping d/λ = 0.1.

Supplementary Methods - Functionality of the polarization analyzer for magnetic field depending on hole diameters and excitation wavelengths

Here, we investigate the effect of hole diameter and excitation wavelength on the functionality of the hole as a polarization analyzer for optical magnetic field. We expect that as the hole becomes larger, its scattering no longer reflects the orientation of the surface current in the *absence of the hole*, thereby losing its functionality. Similarly, as the wavelength becomes smaller, the metal becomes poorer, again losing its functionality.

First, we plot the scattering polarization for various hole diameters for 780 nm wavelength laser excitation. Holes are fabricated on an 80 nm-thick gold film deposited on a sapphire substrate. The incident polarization angle of incident light is fixed at $\phi = 45^\circ$. As shown by both experimental (red circle) and FDTD calculations (blue rectangle) in Supplementary Fig. S1a, for the small hole, the scattering polarization angle $\psi_{sc,\,E}$ (52 degrees) is the same as the angle of the perfect magnetic polarizer, oriented by 90 degrees from the tangential magnetic field. On the other hand, as the diameter of the hole gets larger, $\psi_{sc,\,E}$ deviates from the *perfect magnetic polarizer line* (solid dashed line, defined as $\psi_{sc,\,E}$ at exactly 90 degrees from $\vec{\mathbf{H}}_t$).

The inset shows the experimentally measured scattering polarization for d = 100 nm, where the scattering polarization is perpendicular to the tangential magnetic field, and for d=1000 nm, and finally for d=100 μm where the scattering polarization is along the tangential electric field. These results show that while a smaller hole is always preferable, a diameter $d \sim \lambda/2$ can be used as an acceptable polarization analyzer for optical magnetic field with errors smaller than five degrees.

Second, we plot the scattering polarization for various wavelengths to see the effect of $|\varepsilon|$ on the performance of the polarization analyzer for magnetic field. The hole diameter of 80 nm is made on a 80 nm-thick gold film deposited onto a sapphire substrate. Supplementary Fig. S1b shows experimental data for scattering polarization angle $\psi_{sc,\,E}$ for various wavelengths. The substantial deviation from the *perfect magnetic polarizer line* at shorter wavelengths indicates that 80 nm apertures on gold cannot be used as polarization analyzer for magnetic field for visible wavelengths. Supplementary Fig. S1c shows FDTD simulation, in good agreement with experiments. It should be noted that in both Supplementary Fig. S1b and S1c, the diameter is fixed at 80 nm while the wavelength changes, making the relative hole size larger for shorter wavelengths. To determine whether the increasing error in the visible wavelengths is due to decreasing of $|\varepsilon|$ or due to the increasing of relative hole size, in the inset of Supplementary Fig. S1c we show the result when both the hole size and the wavelength are scaled so that the *ratio* of the hole diameter to wavelength is constant: $\frac{d}{\lambda}$=0.1 (Inset of Supplementary Fig. S1c). The similarity between the result for the fixed hole diameter and the scaled hole diameter suggests that the error originating from the decreasing of $|\varepsilon|$ is chiefly responsible for the increasing error at visible wavelengths. It is expected that with decreasing of $|\varepsilon|$, higher order terms contribute, making simple Leontovich boundary condition no longer valid.