Supporting Online Material for

Probing the Magnetic Field of Light at Optical Frequencies

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This PDF file includes:

Materials and Methods
Supporting Text
References
Materials and methods. We investigate the functionality of the split-probe on two types of ridge waveguide. For both the waveguides we started with a Si wafer of 525 µm thickness with an 8 µm layer of thermal silicon oxide has been grown. The first waveguide has been obtained by growing a 170 nm Si$_3$N$_4$ layer and by subsequently dry etching a straight ridge with a width of 2 µm and a height of 20 nm. The waveguide supports only a weakly guided TE mode. The waveguide has an effective refractive index of $\sim 1.46$ and for an incident wavelength of 1550 nm the wavelength in the structure is $\lambda \sim 1550/1.46$ nm $\approx 1060$ nm. In such a waveguide the longitudinal component $E_x$ of the electric field is maximally 10% of the transverse component $E_y$. $E_x$ has an antisymmetric distribution with respect to the waveguide and its maximum amplitude is located close to the edge of the ridge. We attribute the slight asymmetry of Fig. 3C to the antisymmetric contribution of $E_y$ to the signal detected on Ch2. In order to measure with a rotated probe-ridge orientation, we use another waveguide with two straight sections con-
nected by a 90 degrees bend. To guide the light across the bend a stronger effective refractive
index contrast is required. This is achieved using a 300 nm thick Si₃N₄ layer. This waveguide
is single-mode for TE and TM. The waveguide has an effective refractive index of ∼1.6 and,
thus, the wavelength in the structure is \( \lambda \sim 1550/1.6 \text{ nm} \simeq 970 \text{ nm} \).

**Supporting Text.** A clear understanding of the electromagnetic response of a near-field
probe and the detection of the probed fields is crucial for future development of ‘magnetic’
near-field optics. Here, we provide a brief description of the electromagnetic response of the
near-field probes employed in this investigation and the algebraic relationships necessary to
calibrate the probes themselves.

**Polarizabilities of standard probes.** We consider a standard probe as a metallic ring. Due
to the symmetry of the ring, the in-plane electric polarizabilities \( \alpha_{xx}^{ee} = \alpha_{yy}^{ee} \neq 0 \). Because in
the investigated waveguide the vertical component of the electric field is negligible, we do not
consider the out-of-plane polarizability \( \alpha_{zz}^{ee} \). The linear response of the probe to an in-plane
electric field is an induced in-plane electric dipole moment \( p_j = \alpha_{jj}^{ee} E_j \), where the label \( j \) is
either \( \hat{x} \) or \( \hat{y} \). An electric polarizability has unit of F·m²·s⁻⁴·A⁻²·kg⁻¹.

The only nonvanishing magnetic polarizability of the standard probe is \( \alpha_{zz}^{mm} \), which can
be estimated by Faraday’s law. The probe responds to an out-of-plane magnetic field with an
induced out-of-plane magnetic dipole moment \( m_z = \alpha_{zz}^{mm} B_z \). Due to the small penetration of
the in-plane magnetic field into the metallic ring, the in-plane magnetic polarizabilities can be
considered negligible. A magnetic polarizability has unit of m⁴·H⁻¹·s²·A²·kg⁻¹·m².

**Polarizabilities of split-probes.** We describe the split-probe as a metallic split-ring. The
considerations for the standard probe also apply here for the polarizabilities \( \alpha_{xx}^{ee}, \alpha_{yy}^{ee}, \alpha_{zz}^{ee} \) and
\( \alpha_{zz}^{mm} \), but now \( \alpha_{xx}^{ee} \neq \alpha_{yy}^{ee} \). Moreover, due to the air-gap in the probe, \( B_z \) induces an in-plane
electric dipole moment \( p_x = i \alpha_{xx}^{em} B_z \), where \( \alpha_{xx}^{em} \) is called cross-polarizability. Likewise, \( E_x \)
induces a vertical magnetic dipole moment \( m_z = i\alpha_{xx}^{me} E_x = -i\alpha_{xx}^{em} E_x \). A cross-polarizability has unit of \( s^3 \cdot A^2 \cdot \text{kg}^{-1} \cdot \text{m} \) and describes the optical biaxiality required to convert the magnetic field to an electric field.

**Detection of the probed fields.** As mentioned in the text, only the in-plane \((xy)-plane\) dipole moments induced in the apex of the probe can couple to the probe-fiber. In the most generic case, we therefore obtain \( p_x = \alpha_{xx}^{ee} E_x + i\alpha_{xz}^{em} B_z \) and \( p_y = \alpha_{yy}^{ee} E_y \). Only a fraction of the radiation emitted by these dipole moments couples to the probe-fiber. We define the renormalized electric field \( w \) of light such that the power \( W \) of light is \( W = |w|^2 \). Only a fraction of the radiation emitted by the above mentioned dipoles \( p_j \), where the label \( j \) is either \( \hat{x} \) or \( \hat{y} \), couples to the probe-fiber. Hence, \( w_j \) of light in the fiber mode is proportional to \( p_j \) and, thus, \( w_j = \eta_j p_j \), where \( \eta_j \) is a coupling coefficient (real number). In first approximation \( \eta_j \) can be considered equal for both the magnetically and electrically induced \( p_j \). Note that, as \( W_j = |w_j|^2 \), \( \eta_j \) has unit of \( s^{-5/2} \cdot \text{kg}^{1/2} \cdot A^{-1} \).

The photocurrent \( I_{ph} \) induced in each photodetector is proportional to the total impinging light power \( W_j^{tot} = [w_j + w^{ref}/2 \cdot \{ (|w_j|^2 + (w^{ref}/2)*) = [|w_j|^2 + |w^{ref}/2|^2 + 2w_j w^{ref}/2 \cos \Delta \phi_j] \), where \( w^{ref} \) is the renormalized electric field of the light in the reference branch of the interferometer and \( \Delta \phi_j \) is the phase difference between the electric field of light in the reference branch and the two polarization states (Ch1 and Ch2) in the signal branch. The phase difference \( \Delta \phi_j \) contains two contributions: 1. due to the optical path lengths in the interferometer, which are equal for both channels, and 2. due to the coupling mechanism of the probe, these can be different depending on which field components are probed. Consequently, \( I_{ph} = \sigma_d W_j^{tot} \), where \( \sigma_d \) is the detector sensitivity, and the detector signal turns out to be \( V^d = R_f I_{ph} = R_f \sigma_d W_j^{tot} = R_f \sigma_d [|w_j|^2 + |w^{ref}/2|^2 + 2w_j w^{ref}/2 \cos \Delta \phi_j] \), where \( R_f \) is the feedback resistance of the detector. Therefore \( V_j^d \) can be divided in a DC and AC component \( V_j^d = V_j^{AC} + V_j^{DC} \), where \( V_j^{DC} = C_d [|w_j|^2 + |w^{ref}/2|^2] \), \( V_j^{AC} = C_d w_j w^{ref} \cos \Delta \phi_j \) and
As we use a heterodyne detection scheme, we are able to separate $V_j^{AC}$ from $V_j^{DC}$ (I).

As in the structure investigated $E_x$ is negligible, $V_x^{AC} = iC_d w_{ref} \eta_x \alpha_{xz} E_x \cos \Delta \phi_x$ and $V_y^{AC} = C_d w_{ref} \eta_y \alpha_{yy} E_y \cos \Delta \phi_y$ can be derived. The parameters $\Upsilon_x = \eta_x \alpha_{xz}$ (with unit of s$^{3/2} \cdot$kg$^{-1/2} \cdot$A) and $\Upsilon_y = \eta_y \alpha_{yy}$ (with unit of m$\cdot$s$^{1/2} \cdot$kg$^{-1/2} \cdot$A) describe the coupling between probed fields and near-field probe. By knowing the intensity of the light propagating in the waveguide, $\Upsilon_j$ could be calculated and, thus, the probe calibrated.

From the ratio between the amplitude of Ch2- and Ch1-signal $1 \approx |V_x^{AC}|/|V_y^{AC}| = [\Upsilon_x/\Upsilon_y][B_z/E_y]$ the ratio of the magnetic and electric coupling between light and probe can be derived. In fact, with $\omega B_z = -k E_x$ and thus $v \approx [\Upsilon_x/\Upsilon_y]$, where $v$ is the phase velocity of light propagating in the waveguide. As the magnetic field divided by the phase velocity of light has the same unit as the electric field, we can infer that, in our split-probe, the strength of the electric and magnetic light-probe coupling are comparable.

**References and Notes**