

Plasmonic Effects on Information Flow in Optical Localization Metrology

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Fisher information analysis reveals that in optical localization metrology, plasmonic resonances increase the information content of light diffracted on nanoparticles but have the opposite effect for light scattered from apertures in plasmonic films.

Recent metrological experiments have demonstrated that the dimensions and positional coordinates of nanoscale objects (nanowires/particles/holes/etc.) can be retrieved from their optical scattering patterns, with precision and accuracy reaching the atomic (~ 100 pm) scale.

Here, we show how information on the position of nanoscale objects propagates through scattered light to a detector. Using the approach developed by Hüpfl, *et al.* [1], Fisher information flux $\vec{S}_{FI} = \frac{2}{\hbar\omega} \text{Re}(\partial_\theta \vec{E}_\omega^* \times \partial_\theta \vec{H}_\omega)$, calculated from variations in the scattered electromagnetic fields associated with small changes θ in object position, reveal how plasmonic effects shape the information flow to affect achievable precision in position measurements.

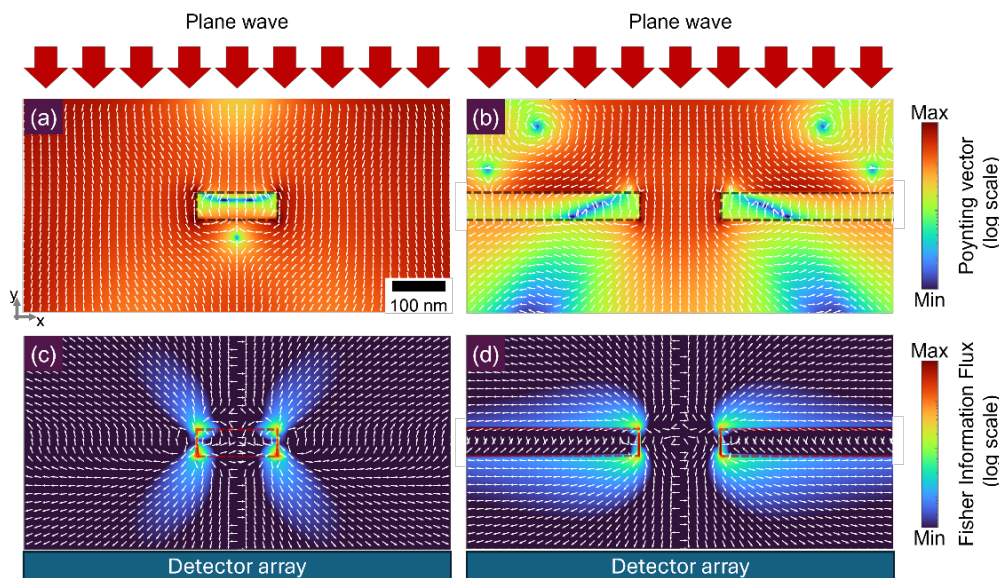


Fig. 1. Measuring nanometric displacement via light scattering – the information aspect. Poynting vector (a and b) and Fisher information flux (c and d) for a gold nanowire (a and c) and a nano-slit in a gold thin film (b and d). We assume structures of infinite extent in the z direction, illuminated along $-y$ with a plane wave ($\lambda = 570$ nm) polarized along x . Fisher information is evaluated for displacements $\theta = 2$ nm in the x direction, assuming a detector of $12 \mu\text{m}$ width in a plane $4 \mu\text{m}$ from the object plane.

Figure 1 shows energy flux and density maps and corresponding Fisher information flux and density maps for two important representative cases: a plasmonic nanowire and a slit in a plasmonic thin film, under plane wave illumination. The information received by a detector array in transmission determines accuracy and precision with which changes in the object's position can be resolved. Our numerical studies reveal that:

- The Fisher information flux does not follow the scattered electromagnetic energy flux;
- Fisher information is concentrated around the sharp edges and corners of the nanostructures;
- In the case of a plasmonic nanowire, information is ‘beamed’ towards the detector. Information reaching a detector of limited size is enhanced by plasmonic resonance effects, thereby improving achievable precision in measurements;
- In the case of an aperture in a plasmonic film, information is channeled along the film. Information reaching the detector is decreased by plasmonic resonance effects, thereby reducing measurement precision.

It is thus vital that plasmonic effects are considered when optimizing apparatus and illumination conditions for optical metrology of plasmonic nanostructures.

[1] J. Hüpfl, F. Russo, L. M. Rachbauer, D. Bouchet, J. Lu, U. Kuhl, and S. Rotter, “Continuity equation for the flow of Fisher information in wave scattering,” *Nat. Phys.* **20**, 1294 (2024).