High-Performance Nanosensors Based on Plasmonic Fano-like Interference: Probing Refractive Index with Individual Nanorice and Nanobelts

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Unlike those propagating at metal/dielectric interfaces, localized collective oscillations of charges confined to the surface of metal nanoparticles can be directly excited by external illumination without the need of any additional coupling-in technique, provided that particles are much smaller than the incident wavelength. These oscillations, which can be pictured as a “wave” of electrons moving across the surface of the particle, are referred to as localized surface plasmon resonances (LSPRs), and they are responsible for nanoparticles’ bright colors when in colloidal suspension, as a result of their intense absorbing and scattering of light in the visible range.

One of the most appealing properties of LSPRs is that their resonant frequency strongly depends on nanoparticles’ size, shape, and composition, as well as on the refractive index of the surrounding medium. Given that present technological advances allow one to control particle geometry down to nanometer scale, spectral shift of LSPRs can then be used to detect extremely small changes of the immediate dielectric environment, for instance, such as those produced by the binding of some biological molecules having a refractive index that is slightly different than that of their solvent. Since the pioneering work of Englebienne in 1998, this feature has raised the prospect of LSPR-based sensors to become highly competitive in label-free bioanalytical sensing, as summarized in recent reviews on the subject.

When assessing the actual performance of a refractive index sensing scheme based on the spectral shift of a given plasmon resonance, we have to first consider its refractive index sensitivity, which is defined as the linear regression slope within a given range for the position of the resonance (either a peak or a dip) as a function of refractive index. This magnitude is usually expressed in terms of wavelength ($\lambda$) or energy ($E$) shifts per refractive index unit (RIU), and it provides a preliminary measure of the sensor quality. However, sensitivity alone cannot fully characterize the sensor performance unless ideal conditions are assumed, namely zero system noise and infinitely high spectral resolution. Sherry et al. therefore, proposed the so-called figure of merit (FoM), which is defined as the plasmon resonance sensitivity divided by its “full width at half-maximum” (fwhm), as the most meaningful indicator for evaluating the performance of these sensors.

**ABSTRACT**

We propose two different configurations for which the Fano-like interference of longitudinal plasmon resonances occurring at individual metallic nanoparticles can be easily employed in refractive index sensing: a colloidal suspension of nanospheroids (nanorice) and a single nanowire with rectangular cross section (nanobelt) on top of a dielectric substrate. We numerically study the performance of the two in terms of their figures of merit, which are calculated under realistic conditions. For the case of nanorice, we explicitly incorporate the effect of size dispersity into the simulations. Our obtained results show that the application of the proposed configurations seems to be not only feasible but also very promising.

**KEYWORDS:** plasmonics · Fano resonances · individual nanoparticles · nanorice · nanobelts · LSPR sensing

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LSMR-based sensors. Such dimensionless quantity allows one to directly compare the sensing properties of different systems irrespective of their shape, size, and operating wavelength. Hence, it has become a standard benchmark in the field, although alternative figures have also been proposed for fixed-wavelength measurements and thin coating configurations. Although not discussed any further throughout this work, we also have to note that the FoM is inversely proportional to the detection limit of the sensor (that is, the smallest refractive index change that can accurately be measured) assuming the FWHM as a crude approximation of the effective spectral resolution.

According to its very definition, the optimal FoM would then be obtained from those resonances exhibiting both high sensitivity to environment and narrow FWHM, which are precisely the main features of spectral line profiles arising from Fano interference.\textsuperscript{14,15} Such an interaction of discrete and continuum-like states (often labeled as “dark” and “bright” modes) has already been employed for refractive index sensing by means of either propagating\textsuperscript{16–21} or localized plasmon resonances.\textsuperscript{22–28} In this paper, we propose that the Fano-like interference of longitudinal plasmon resonances occurring at individual elongated metallic nanoparticles\textsuperscript{29} be employed for refractive index sensing. More precisely, we consider two different single-particle configurations that are easily attainable and, in contrast to some previous proposals,\textsuperscript{24,26,28} do not require sophisticated geometrical arrangements at the nanoscale: a colloidal suspension of nanospheroids (nanorice) and a single nanowire with rectangular cross section (nanobelt) on top of a dielectric substrate. We numerically obtain their expected performance in terms of their FoMs, which are calculated under realistic conditions by means of the separation of variables (SVM)\textsuperscript{30} and the finite element (FEM)\textsuperscript{31} methods (see Methods section for a succinct description of calculation techniques). For the case of colloidal nanorice, we also explicitly incorporate size dispersity into our simulations and discuss its influence on the averaged spectral response.

RESULTS AND DISCUSSION

Colloidal Nanorice. The first configuration we are proposing is based on the sharp peak arising in the scattering spectra of individual Ag nanorice particles (i.e., elongated Ag nanospheroids) as a result of the interference between the fundamental longitudinal LSPR and the next odd-order mode. As discussed in a previous work,\textsuperscript{29} such an interaction can be easily understood in terms of a Fano-like interference model where the asymmetry parameter is close to unity, which originates a narrow, asymmetric peak in spectral lines. In order to illustrate this phenomenon, we present in Figure 1a the SVM calculation for the scattering efficiency, \( Q_{\text{eff}} \), of a single Ag nanospheroid with total length \( L = 345 \) nm and maximum diameter \( D = 30 \) nm embedded in a dielectric medium with refractive index \( n_d = 1.5 \). Incident field is TM-polarized and perpendicular to the rotation axis. (b) Calculated scattering efficiencies for random orientation and different values of \( n_e \). Different curves are artificially shifted for the sake of clarity. (c) Linear scaling of the position of peaks inside the dashed box in panel (a) as a function of \( n_e \). The solid line marks the linear regression curve. Obtained values for \( S_L \) and the range of FoMs are also shown.

Figure 1. (a) Calculated scattering efficiency of a single Ag nanospheroid (\( L = 345 \) nm; \( D = 30 \) nm) surrounded by \( n_d = 1.5 \). Incident field is TM-polarized and perpendicular to the rotation axis. (b) Calculated scattering efficiencies for random orientation and different values of \( n_e \). Different curves are artificially shifted for the sake of clarity. (c) Linear scaling of the position of peaks inside the dashed box in panel (a) as a function of \( n_e \). The solid line marks the linear regression curve. Obtained values for \( S_L \) and the range of FoMs are also shown.
that the most intense interaction between a pair of metallic nanorods arises for their end-to-end aligning along their long axis under TM-polarized light. In such a scenario, the occurrence of interparticle plasmon coupling can be easily monitored by means of the spectral red shift of the dipole-like resonance \( \Delta \lambda / \lambda_0 \). As we do not have knowledge of any experimental report on plasmon coupling between elongated silver nanoparticles in the near-infrared (NIR) range, let us assume that \( \Delta \lambda / \lambda_0 \) follows the so-called “plasmon ruler equation” proposed by Jain et al.,38 which has been found to be in good agreement with experimental measurements of silver nanosphere pairs in the same frequency range.39 Hence, we expect plasmon coupling (and therefore multiple scattering effects) to be negligible for \( d/L \gtrsim 0.23 \), where \( d \) is the interparticle end-to-end separation. Being even more cautious, let us consider \( d = 100 \) nm to be the minimum acceptable distance for nanorods with \( L = 345 \) nm. For a cubic cell of size \( d + L \), this results in a maximum concentration of \( \sim 10^{13} \) particles per milliliter to ensure a dilute regime.

For so well-dispersed nanoparticles, we can assume that their relative spatial and polarization orientations with respect to the incident light are randomly distributed, so that their global response is averaged over all possible TM and TE configurations (see schematic picture in Figure 1a). Therefore, the scattering efficiency for random orientation is given by\(^{32,40,41} \)

\[
Q_{\text{sca}}^{\text{rand}} = \left\langle \frac{1}{2} \left[ Q_{\text{sca}}^{\text{TM}}(\alpha) + Q_{\text{sca}}^{\text{TE}}(\alpha) \right] \right\rangle _\alpha
\]  

where the angular brackets \( \left\langle \ldots \right\rangle _\alpha \) denote averaging over all possible orientation angles \( \alpha \).

In Figure 1b, we explore the evolution of spectral features in \( Q_{\text{sca}}^{\text{rand}} \) as a function of the external refractive index \( n_a \) for the same \( L \) and \( D \) as in panel a. Please notice that different curves are artificially shifted for the sake of clarity. As can be seen for \( n_a = 1.5 \), probing over oblique incidences produces a global quenching of peaks’ intensities, in addition to the emergence of a small signature of the even-order mode between the two. With respect to refractometric sensitivity, it is apparent that the peak located at \( \lambda = 840 \) nm strongly blue shifts as the refractive index decreases. Nevertheless, its narrow width is preserved for the choice of \( \{n_a\} \) values, which are uniformly distributed between those corresponding to water \( (n_a = 1.33) \) and usual index matching oil \( (n_a = 1.5) \). For a numerical evaluation of their FoMs, the position of the peaks inside the dashed box is plotted against refractive index in Figure 1c. The resonant wavelength shows a clearly linear dependence on \( n_a \), exhibiting a \( \pm 93 \) nm shift between the most distant values. The obtained refractive index sensitivity \( S_\lambda = 547.5 \) nm/RIU results in remarkably high FoMs ranging from 20.9 for \( n_a = 1.5 \) to 27.2 for \( n_a = 1.33 \). Hence, the application of the proposed configuration seems to be not only feasible but also very promising.

To end our discussion on the attainability of refractive index sensing by means of colloidal nanorods, we now focus on the effect of size dispersity in the spectral response of a collection of nanospheroids. As a first approximation, we could consider that the distributions of total length and maximum diameter are statistically independent from each other when their deviations from the mean values \( L \equiv 2a_0D \equiv 2b_0 \) are small enough.\(^{42} \)

Assuming that the major and minor semiaxes \( a,b \) are distributed within the intervals \([a_0 - \Delta a_0,a_0 + \Delta a_0] \) and \([b_0 - \Delta b_0,b_0 + \Delta b_0] \) according to a random process with probability density functions \( p(a),q(b) \), respectively, the size-averaged scattering efficiency is given by

\[
Q_{\text{sca}}^{\text{pol}}(a,b) = \int_{a_0 - \Delta a_0}^{a_0 + \Delta a_0} da \int_{b_0 - \Delta b_0}^{b_0 + \Delta b_0} db q(b) Q_{\text{sca}}^{\text{pol}}(a,b) \]  

(2)

where “pol” denotes either TM or TE polarization. For the sake of simplicity, we impose \( p(a),q(b) \) to be Gaussian distributions with means \( a_0,b_0 \) and standard deviations \( a_0,b_0 \) defined as

\[
a_{\alpha,b} = \frac{\Delta a_0,b_0}{n_{\alpha,b}}
\]  

(3)

with \( n_{\alpha,b} \) being integer numbers. Substituting for \( Q_{\text{sca}}^{\text{pol}} \) from eq 2 into eq 1 gives the now size-averaged scattering efficiency for random orientation

\[
\tilde{Q}_{\text{sca}}^{\text{rand}} = \left\langle \frac{1}{2} \left[ Q_{\text{sca}}^{\text{TM}}(\alpha) + Q_{\text{sca}}^{\text{TE}}(\alpha) \right] \right\rangle _\alpha
\]  

(4)

In order to determine the eventual effects of size dispersity in the above-obtained FoMs, we have performed extensive simulations for different values of \( \Delta a_0,b_0 \) and \( \sigma_{a,b} \) (see Supporting Information for details). Summing it up, we have concluded that (i) the effect of size dispersion is negligible with respect to that of \( a \) for the same ratio of mean to standard deviation, as expected from the spectrum’s being governed by longitudinal modes, and (ii) that the intensity of the resonance in the most favorable configuration (i.e., TM polarization and normal incidence) decreases down to 50% for \( \Delta a_0,a_0 > 0.05 \). Given that random orientation additionally quenches the spectra, we have assumed 5% as our operating size dispersity value. Although presently existing samples of silver nanorods are still more disperse (Liang et al.\(^{35} \) report \( \Delta a_0/a_0 \sim 0.15 \) for \( L \sim 300 \) nm), we find that such a value falls within the commonly accepted standards of nanoparticle synthesis and could be reasonably attained in the near future.

In Figure 2, we present the calculated \( \tilde{Q}_{\text{sca}}^{\text{rand}} \) in the vicinity of the Fano peak for a single Ag spheroid \( (L = 2a_0 = 345 \) nm; \( D = 2b_0 = 30 \) nm) surrounded by \( n_a = 1.41 \), assuming \( \Delta a_0,a_0 = 0.05;\Delta b_0 = 0 \) and increasing...
values of $\sigma_{\lambda}$ (see the upper left inset for $p(\alpha)$ profiles). For the sake of comparison, the calculation for monodisperse spheroids is also shown (dashed curve). We have chosen this precise refractive index as a representative sample of our systematic study on the influence of size dispersity in the figures of merit for the set of values consisting of $\{n_d\} = \{1.33,1.37,1.41,1.45,1.5\}$. As can be seen, increasing standard deviation results in both the flattening and the broadening of the resonance. Hence, the fhwm almost duplicates from $\sigma_{\lambda}/\Delta a_0 = 0.1666$ to $\sigma_{\lambda}/\Delta a_0 = 0.5$, although the central wavelength remains nearly unchanged.

Consequently, the effect of size dispersity on the global response over $\{n_d\}$, which is summarized in Table 1, can be considered as neutral form the point of view of refractive index sensitivity. On the other hand, minimal and maximal FoMs (i.e., those corresponding to $n_d = 1.5$ and $1.33$, respectively) reduce by half ($16.6,18.9$ vs $8.6,10.2$) as $\sigma_{\lambda}/\Delta a_0$ goes from 0.1666 to 0.5. Remarkably, the obtained values for this latter case are about three times smaller than those obtained by us, as far as they are associated with the lowest, dipole-like resonance, which lacks the narrow, asymmetrical line shape originated by Fano-like interference.

**Individual Nanobelt on Top of a Dielectric Substrate.** Next, we consider the case where an individual metallic nanobelt (that is, a nanowire with rectangular cross section $W \times H$, also referred to as a “nanostripe”) is deposited onto a dielectric substrate. In our previous paper,29 we showed that the scattering spectrum at normal incidence of a metallic nanowire embedded in a dielectric medium is also governed by the Fano-like interference of longitudinal modes, provided that its cross-sectional aspect ratio (cAR $\equiv W/H$) is high enough. However, the assumption of particles being well-dispersed (i.e., non-interacting) in eq 1 seems to be less realistic for actually synthesized gold nanobelts,45,46 given that they can be described as infinitely long for all practical purposes. Consequently, we will focus our attention on the nanobelt-on-substrate geometry as a simplified version of the nanorod-on-substrate sensing arrangements that have already been experimentally implemented.47–49

According to recent reports, gold nanobelts/nanostripes of several tens of nanometers in their cross-sectional height $H$ can be efficiently fabricated by means of either chemical45,46 or lithographic techniques.50–53 Assuming $H = 20$ nm to be the operating value, we present in Figure 3a the scattering efficiency calculated by means of FEM for an infinitely long gold rectangular nanowire with $W = 400$ nm that is located on top of a dielectric substrate with refractive index $n_s = 1.5$ and surrounded by a cover medium with $n_c \leq n_s$. Light is TM-polarized and impinges at normal incidence. As previously described by other authors,22,23 we have defined the excitation by means of the Fresnel coefficients at the interface between cover and substrate semispaces. The scattering efficiencies for $n_c = 1.33$ and 1.5 are then computed by integrating the scattered power over a circumference enclosing the nanobelt.

As can be seen, the Fano-like interaction between the fundamental resonance and the next odd-order mode does not completely cancel the scattering intensity, unlike that for nanospheroids in Figure 1. Rather, the minimal values are about 40% of those of

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tical from the experimental point of view.
In order to obtain realistic estimates, we have then
adopted a dark-field-like configuration where the incident
light impinges obliquely over the nanobelt and the
scattered efficiency is only computed over the arc defined
by a given numerical aperture (NA) with respect to
the surface normal (see scheme on top of Figure 3b).
Assuming NA ≡ n_e sin θ_max = 1.2, which is typical of
water immersion objectives, we present in Figure 3b
the corresponding scattering efficiencies calculated at
oblique incidence (α = 35°) for the same nanobelt and
substrate as in panel a and different values of n_e.
In contrast to the case of normal incidence and full
collection, the lowest even-order resonance is clearly
apparent, whereas the dipole-like one is partially sup-
pressed due to the importance of contributions with
θ > θ_max. On the other hand, the 3λ/2-like resonance
still remains in sight due to its much more anisotropic
radiation pattern. Hence, it can be useful for our
purposes. The obtained refractive index sensitivity
for such configuration within the range [1.33,1.5] is
S_1 = 145.7 nm/RIU, which remarkably results in its FoMs
ranging from 5.8 for n_e = 1.5 to 9.1 for n_e = 1.33.

Going beyond the proof of principle raises the
question of whether there is an optimal configuration
that maximizes the figure of merit within a given
refractive index range. First of all, the combination of
such values with a particular experimental setup will
determine the attainable collection and incidence
angles. Next, we have to decide the cross-sectional
height H (that is the film thickness, lithographically
speaking): provided that the nanobelt is wide enough
to sustain a 3λ/2-like resonance, its wavelength will
scale inversely with H, but no transversal features
become apparent in the scattering spectrum for sys-
tems with H ≪ W. Consequently, we can take it just as a
fabrication constraint. For a given H, we then have to
determine the corresponding minimal cross-sectional
width that allows one to reasonably resolve the 3λ/2-
like resonance. This requires that the leading contribu-
tion to scattering be sufficiently detected by our optical
setup. In addition, the operational wavelength range
defined by [λ^{(3)}_{res}(n_e = 1.33),λ^{(3)}_{res}(n_e = 1.5)] both red shifts
and widens as cAR increases, given that the position
of longitudinal resonances is proportional to W and the
refractive index sensitivity S_1 linearly scales as a function
of aspect ratio, as one can understand from simple quasi-
static considerations.54 Besides, we have to take into
account the evolution of the fwhm values, which may
also make S_1 and FoM have an opposite dependence on
cAR, as it has already been reported by Becker et al.12

An illustrative example of this multivariate scenario
is presented in Figure 4 for a gold nanobelt with
H = 20 nm on top of a dielectric substrate with n_e = 1.5.
Open symbols mark the positions of 3λ/2-like reso-
nances in Q^{NA=1.2}_res(α = 35°) for n_e = 1.33 (circles) and
n_e = 1.5 (squares) assuming different values of W. As
expected, the resulting operational wavelength range
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regard to this, we might note in passing that the
position of resonances can be fairly well approximated
dashed lines) by a semianalytical effective wavelength
model (see Methods section), which has allowed us to
optimize our numerical efforts. We have decided
W = 400 nm (dotted line) to be the minimal value that

Figure 3. Calculated scattering efficiency of a single Au
nanobelt (W = 400 nm; H = 20 nm) located on top of a
dielectric substrate with n_e = 1.5 and surrounded by a cover
medium with n_e ≤ n_s. (a) Normal incidence and (b) oblique
incidence (α = 35°) assuming NA = 1.2. The upper right inset
depicts the line profiles at the vicinity of the Fano peak.

the maxima for the broad, dipole-like peaks. Anyway,
the position of the resonance red shifts by 25 nm as n_e
increases from 1.33 to 1.5, which permits a direct monitor-
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METHODS

Calculation Techniques. Calculations for spheroids are performed by means of a modified version of the F77-code made publicly available at the Web site of the Jena-St.Petersburg Database of Optical Constants (JPDOC)\textsuperscript{55} in which both eq 1 and eq 4 have been incorporated. A detailed description of SVM formalism can be found in ref \textsuperscript{30}.

Gaussian probability distribution function for major semi-axis around $a_0$ is defined as

$$p(a) = Ae^{-|a-a_0|^2/2a_0^2}$$

where $A = a_0/(2\pi)^{1/2}erf(n_{av}/\sqrt{2})$ so that

$$\int_{a_0-\Delta a_0}^{a_0+\Delta a_0} dap(a) = 1$$

For the evaluation of $Q_{\text{esc}}^\text{cfa}$ in eq 4, we have used a combination of Romberg's and Gauss-Hermite's numerical quadratures.\textsuperscript{25}

Results in Figures 3 and 4 are obtained by using the electromagnetic waves part of the radio frequency module of the finite-element method based COMSOL v4.2 commercial software. The simulation space consisted on a rectangle of two concentric circles of radii $R_{\text{in}}=1 \mu m$ and $R_{\text{out}}=1.5 \mu m$, which generate two subdomains, a circle and an annulus. Those subdomains were further split into two equal parts by a line to represent the glass substrate and the cover medium. The rectangle is located on top of that line and inside the cover medium domain. The two half annulus were set to be cylindrical perfectly matched layers (PML) to absorb all outgoing radiation, each with material properties equal to the adjacent circular subdomain. We have used the scattered field formulation to explicitly write the incident field above the substrate as a sum of longitudinal plasmon resonances at individual metallic nanoparticles can be employed for refractive index sensing in at least two different configurations. For the first of them (a colloidal suspension of randomly oriented Ag nanorice), we find that a FoM $\sim 25$ seems to be attainable within the 1.33–1.5 refractive index range. These values are clearly reduced when size dispersity is explicitly taken into account, but we still obtain FoM $\approx 10$ within a 5% size uncertainty. Although such an upper bound for size dispersity is still smaller than that experimentally measured, we expect it to be reasonably feasible with further refinements of nanorice synthesis. As attained, the expected FoMs are fairly as good as (or even better than) those measured for different lithographic realizations of LSPR-based sensors in the NIR range.

In our second proposal (that is, a single Au nanobelt on top of a dielectric substrate), we could, in principle, disregard size dispersity, provided that the sample is obtained by lithographic techniques. On the other hand, the actual implementation of this approach requires the collection of scattered intensity within a finite numerical aperture, which determines the minimal incidence angle for excitation and imposes the minimal cross-sectional width that guarantees a sufficient signal collection for a given metal thickness. Our study for $H = 20 \text{ nm}$; $W = 400–700 \text{ nm}$ shows that obtained values for the figure of merit and refractive index sensitivity are governed by the nanobelt's geometry, on which they depend oppositely ranging from $S_1^w = 145.7 \text{ nm/RIU}$, (FoM$^\text{cfa}$) = 7.4 for $W = 400 \text{ nm}$ to $S_1^w = 288.2 \text{ nm/RIU}$, (FoM$^\text{cfa}$) = 3.0 for $W = 700 \text{ nm}$. This opens the possibility of their tailoring to one’s best convenience.

Finally, we want to remark that we expect our two proposed configurations to be experimentally tested in the near future, as they do not require other nanoscale arrangement than the actual supply of suitable elongated nanoparticles with controlled size dispersity.

CONCLUSIONS

We have demonstrated that Fano-like interference of longitudinal plasmon resonances at individual metallic nanoparticles can be employed for refractive index sensing in at least two different configurations. For the first of them (a colloidal suspension of randomly oriented Ag nanorice), we find that a FoM $\sim 25$ seems to be attainable within the 1.33–1.5 refractive index range. These values are clearly reduced when size dispersity is explicitly taken into account, but we still obtain FoM $\approx 10$ within a 5% size uncertainty. Although such an upper bound for size dispersity is still smaller than that experimentally measured, we expect it to be reasonably feasible with further refinements of nanorice synthesis. As attained, the expected FoMs are fairly as good as (or even better than) those measured for different lithographic realizations of LSPR-based sensors in the NIR range.

In our second proposal (that is, a single Au nanobelt on top of a dielectric substrate), we could, in principle, disregard size dispersity, provided that the sample is obtained by lithographic techniques. On the other hand, the actual implementation of this approach requires the collection of scattered intensity within a finite numerical aperture, which determines the minimal incidence angle for excitation and imposes the minimal cross-sectional width that guarantees a sufficient signal collection for a given metal thickness. Our study for $H = 20 \text{ nm}$; $W = 400–700 \text{ nm}$ shows that obtained values for the figure of merit and refractive index sensitivity are governed by the nanobelt's geometry, on which they depend oppositely ranging from $S_1^w = 145.7 \text{ nm/RIU}$, (FoM$^\text{cfa}$) = 7.4 for $W = 400 \text{ nm}$ to $S_1^w = 288.2 \text{ nm/RIU}$, (FoM$^\text{cfa}$) = 3.0 for $W = 700 \text{ nm}$. This opens the possibility of their tailoring to one’s best convenience.

Finally, we want to remark that we expect our two proposed configurations to be experimentally tested in the near future, as they do not require other nanoscale arrangement than the actual supply of suitable elongated nanoparticles with controlled size dispersity.
an incident plane wave plus the correspondent component reflected by the interface, whereas only the transmitted component is considered below the substrate. The scattering cross efficiency was computed by integrating the outgoing time-averaged point scattering vector of the pointed fields over an auxiliary circumference of radius $R_{aux} = 0.8 \mu m$ and normalizing it by the incident radiation power and the projected cross-sectional width. The presence of an optical instrument aimed to collect the light with a given numerical aperture was simulated by integrating only over the arc length subtended by the maximum angle allowed by that NA in the cover medium.

The meshing process was done with the built-in algorithm of COMSOL. We restricted the mesh to have a maximum element size (MES) of 1 nm for elements along the line representing the interface. The MES represents the maximum size allowed for the edges of the triangles under this restriction. The same MES of 1 nm was imposed for the mesh of the whole nanobelt. In both cases, we imposed a maximum element growth rate (MEGR) of 1.1, meaning that adjacent elements to a given one should not be bigger than 1.1 times the size of it. For all the other domains, a MES of 25 nm was imposed, while keeping the MEGR to 1.1. Multifrontally massively parallel sparse direct solver (MUMPS) was used to solve the resulting linear system, requiring about 6 GB of memory.

The estimates for $W$ versus $\Delta_{eff}$ in Figure 4 are calculated by means of the resonance condition of a half-wave antenna, assuming the effective wavelength $\lambda_{eff}$ to be that of the symmetric confined mode propagating across a thin metal film surrounded by two different dielectric media. In addition, the values of $W$ have been then corrected in order to take into account the reactivity of nanowire ends.

The analytical forms for the dielectric functions of Ag and Au have been obtained by fitting the measured optical data with a sum of Lorentzian terms.

Conflicts of Interest: The authors declare no competing financial interest.

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Supporting Information Available: Details on the influence of $\Delta_{res} \Delta_{qd0}$ and $\Delta_{res} \Delta_{qsd}$ on the size-averaged scattering efficiency of Ag nanospheroids. This material is available free of charge via the Internet at http://pubs.acs.org.

REFERENCES AND NOTES


