RESEARCH ARTICLE

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Controlling the Response of Plasmonic Nano-Antennas through Gap-Loading

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Abstract

Unlike previously reported works, in this paper, we aim to create a link between the radiating elements and the proposed device at a distance, so that the emission can be distantly and freely manipulated. We present here a new type of device, using nonlinear hybrid antenna-semiconductor interaction. We observe a picosecond transient response from the antenna that cannot be explained by either pure or antenna nonlinearities independently. We have shown that optical pumping of antenna-semiconductor interaction leads to a local reduction of the free-carrier density in the substrate. The transient nonlinear response of the antenna-semiconductor interaction hybrid shows a redshift of the plasmon resonance, as opposed to transient bleaching on SiO_2.

Keywords: Controlling, Nano-antennas, Nanoparticle, Plasmonics.

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Introduction

We study the dependence of the hybrid interaction on several experimental parameters, including the polarization of excitation and detection.

Nanoscale plasmonic components, such as, nano-antennas, are of enormous interest for their capabilities of locally enhancing electromagnetic fields and controlling emission. Active control of such components will enable a new generation of tunable devices. We recently introduced a new concept of antenna switches relying on photoconductive loading of the gap between the arms of a dimer antenna. Experimentally, modulation of localized plasmon modes has been achieved using the refractive index of liquid crystals. Active tuning of the antenna gap has also been demonstrated using mechanical means, such as, using stretchable elastomeric films. We demonstrated experimentally.[1] For indium tin oxide (ITO), unity order changes of the refractive index have been achieved by applying an electric field.

Here, we present a detailed study of the response of antennas on 20 mm thick antenna-semiconductor interaction film (low cost), both with and without antenna-semiconductor interaction cover layer. We find an effect for both perpendicular and parallel modes of the antenna, although the parallel mode shift is more pronounced, as well as, a polarization dependence of the pump beam. Additionally, we look at the interaction of a larger cylindrical gold pad with the antenna-semiconductor interaction surrounding it to further investigate the injection mechanism of fast electrons from the gold into the antenna-semiconductor interaction. Nano-antennas were fabricated with e-beam lithography on low-conductivity (70–100 Ω/sq, 20 nm thick) and high-conductivity (8–12 Ω/sq, 120 nm thick) substrates from Sigma. Transformation optics (TO) has now attracted many peoples' interest due to the manipulation feature of the electromagnetic (EM) waves in a user-defined manner. Ever since the proposal reported, the transformation optics concept has motivated a series of studies on other functional and conceptual devices in the field of wave-guiding, and the field of antennas and lenses, such as, focusing devices, directive antennas, and multibeam and isotropic emissions. Moreover, the techniques of source transformation have opened new ways for the design of active devices with source distribution recessed in the transformed space.[2,3]

Apart from other transformation optics-based devices, the illusion devices are also important that can fool the viewer into making the wrong decisions. For example, an object can be made to appear like we can modify the sources and virtually delocalize the emission point when the active sources are unbounded with the medium. In other words, is

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it possible to distantly generate the radiation of the radiating elements, such that, we have the impression that the emission like coming from a virtual source at another location, or where no radiator is physically present.[4]

The transformation to prove that it is possible to generate the desired emission from the source where no actual or certain distance can be achieved by embedding a mapped medium into a transformed medium, whose constitutive parameters are obtained by judiciously squeezing the larger space, excluding antenna aperture, into a compressed region. The beauty of the proposed design is that the transformed medium at a certain distance will behave exactly the same as the original medium bounded with the antenna.

The radiation pattern of the source can be distantly and freely manipulated. A simple antenna source is manipulated to achieve the desired radiation pattern, while the antenna source is not physically in contact with the proposed device, in a different position, instead of its real physical location. Based on this, the proposed non-contact device is used to achieve the functionality of the parabolic antenna from the point source. Finally, yet importantly, the proposed device enables active scatterer, and the device is placed at a certain distance from the active sources. The proposed concept can enhance the potential of antennas for remote controlling applications and in the other fields. The full-wave finite element method is used to verify the expected behavior of our proposed concept in distantly and freely manipulating the radiation patterns.[5]

Material and Methods

The non-contact device is a homogeneous transformation method. For the transformation functions for compression of region are:

$$\gamma' = \frac{a}{c}\gamma + \gamma_O\left(1 - \frac{a}{c}\right)$$

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$$z' = z$$

Then, the constitutive parameters will become:

$$\varepsilon_l = \mu_l = \text{diag}\ [1,1,(c/\alpha)2]$$

Assuming the material parameters of the medium is $s = 40y + 3$, then the parameters of its corresponding image in real space:

$$\varepsilon_{image} = \mu_{image}$$
$$= [1, 1, s_{image}\ (c/\ \alpha)2]$$
$$e\ s_{image} = 40\ y_{image} + 3, \text{ and}$$
$$y_{image} = c/\alpha[y' - y_O + O\ \alpha/c]$$

The constitutive parameters will become:

$$\varepsilon_{ll} = \mu_{ll} = \text{diag}\ [k_1, r_1,/r, k_2 r/r_1,\ k_2 r_1/r]$$
$$e\ k_1 = (a - b)/)(c - b),$$
$$1/k_1,$$
$$r = \sqrt{(\chi - \chi_o)^2 + (\gamma - \gamma_o)^2},$$

$$r_1 = \frac{r(c-b) - b(c-a), \text{ and}}{a-b}$$

$$\phi = \tan^{-1}(\gamma - \gamma_o)/(\chi - \chi_o)$$

In this way, the diamond shaped antenna arrays are transformed into a linear array, with the material parameters of the first quadrant is:

$\varepsilon_{\Delta ABO} = \mu_{\Delta ABO}$. In the second step,

$$= \begin{bmatrix} 4 & 1 & 0 \\ 1 & 0.5 & 0 \\ 0 & 0 & 0.5 \end{bmatrix}$$

after recalling the material parameters will turn to $\varepsilon_{\Delta ABO} = \mu_{\Delta ABO}$, for the

$$= \begin{bmatrix} 4 & 1 & 0 \\ 1 & 0.5 & 0 \\ 0 & 0 & 0.5\ (c/\alpha) \end{bmatrix}$$

Hereafter, equations are used to obtain the constitutive. The working phenomenon of the non-contact illusion device that distantly delocalizes the emission of the antenna into a desired manner. The emission of the radiating antenna in free space is in the forward direction, which device observer outside the non-contact device has the impression that the radiation comes from another emitting antenna's direction, which is optically equivalent. The compressed region is further coated with the complementary medium by folding the space $b < r < c$ into $a < r < b$. In this condition, the resultant device will behave like a transform.[6]

The dynamic flow of the quantum dots was recorded using different excitation powers. The minimum power form in which the photoluminescece (PL) signal from the quantum dots passing through the plasmonic hot spot is detectable is 4 μW; at μW PL signal is detectable even without the antenna, and at around 150 μW, the gold antennas melt and lose their shape. Figure 1 shows a scattering plot, where the height of each peak has been plotted against its during (Δt) for different time scans obtained with 40 μW excitation

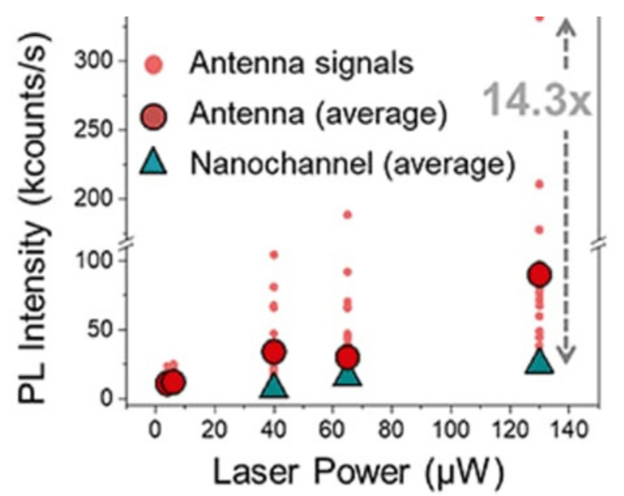

Figure 1: PL intensity

power. We differentiate three types of peak: those obtained at nanochannels, the narrow sharp peaks from the antenna, and the base peaks from the antenna signals. The marks from the antenna peaks are scattered around 0.5 seconds duration for this laser power and are spread at intensities higher than 20 kilo counts per second. The marks from the nanochannels peaks and antenna base peaks are scattered along longer times, and have lower intensities, below 20 kilo counts in all the cases.[7,8]

Result and Discussion

The principle of the proposed device allows shifting the radiation pattern compared to the actual emission. Indeed, the detector of the radiation pattern of the source placed beside the non-contact device will observe a different radiation pattern. In this sense, the observer will have the impression that antenna with reference, and the proposed non-contact device, the radiated field emitted by the real source is presented. The medium that created a different radiation pattern, while depicts the corresponding functionality of the proposed non-contact device with a similar current source, as it is clearly illustrated that the real source is transformed into a virtual one, which is explained by the nature of transformation.[9-12]

Conclusion

In conclusion, we proposed three different devices to distantly and freely manipulate the radiation patterns of antennas with a multi-folded method. The structure of the proposed non-contact device contains a mapped medium, embedded in the compressed region, and covered by the folding region with negative index materials. We illustrated the proposed concept with detailed numerical simulations for each case of different proposed antenna devices and confirmed that the illusion of active scatterer could be distantly achieved. This proposed concept will be very helpful for the future.

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