NANO LOOP OPTICAL ANTENNA

Hengjiang Ren and Zhongxiang Shen

School of Electrical and Electronic Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798.

Introduction

Optical antennas are a fairly new concept and are able to manipulate and control light on a scale much smaller than the wavelength [1]. It is a subject receiving extensive attention in physics, optics and antenna engineering in the past few years due to their potential of enhancing the efficiency of photo-detection, light emission, sensing, heat transfer and spectroscopy [2].

Various optical antennas have been recently studied in the literature. Among them, the gold dipole antenna [1] was the first one fabricated in the nanometer-scale. Other types of antennas studied include cross-dipole [3] for circular polarization, bow-tie slot antenna [4], optical monopole antenna [5], Yagi-Uda nano antenna [6] etc. Although the operation of these optical antennas is very similar to that of their RF and microwave counterparts, there are a few distinct differences between them, such as sub-wavelength dimensions in the nano-meter scale for optical antennas and lack of perfect conductor at the optical frequencies.

This paper describes a preliminary study of a nano loop optical antenna made of gold residing on a fused silica substrate. The loop antenna structure [7] is simulated with a gap source feed using Ansoft's high frequency structure simulator (HFSS). Simulated results are presented and discussed for the antenna's input impedance and radiation pattern.

Description of the Nano Loop Antenna

A sketch of the nano-loop antenna structure is shown in Fig. 1. Gold is chosen as the antenna material forming a circular loop and the loop antenna is fed by a gap source. A lumped port of 1V voltage source is assumed across the feeding gap and it is used to excite the loop antenna. A wavelength of 800nm is considered for the light radiation. Similar to [3, 8], the complex permittivity of gold is taken to be $\varepsilon_r = -26.64 + i1.66$ at this wave length. The gold loop is placed right on a fused silica substrate ($\varepsilon_r = 2.11$) while the upper half-space is assumed to be vacuum.

The circular ring/loop is of a height of $h=20nm$. The thickness, which is the difference between outer and inner radii of the ring, is $a=20nm$. Therefore the gap source is a similar cube of side length 20nm. The feeding gap where the voltage source is located is along the x-axis.

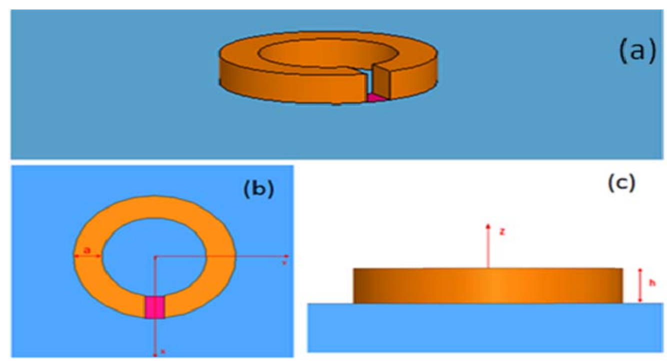

Fig. 1 Sketch of the proposed nano-loop antenna (a) and of its top-view (b) and side-view (c).

Results and Discussions

In order for the loop antenna to resonate at a wavelength of 800nm, the diameter of the gold loop is adjusted. Through a number of simulations, we find that the nano-loop will be resonant at 800nm when the circumference of the gold loop is 287nm, or about 0.36 wavelengths. This dimension is much smaller than $0.79\lambda_0$ (first resonance) and $1.13\lambda_0$ (second resonance), which are required by a normal printed loop antenna operating at the microwave frequency [7].

Using the obtained circumference for the gold loop we then perform the frequency sweep to study the frequency response of the loop antenna. Fig. 2 shows the simulated input impedance at the feeding gap of the gold loop antenna. It is seen that the loop resonates at $0.36\lambda_0$. It is also noted that the input resistance at the resonance is about 1160Ω, which is much larger than that of a normal loop antenna at its first resonance [7], but small than that of a normal printed loop at its second resonance. It should be mentioned that 800nm is the first resonance of our proposed nano-loop antenna.

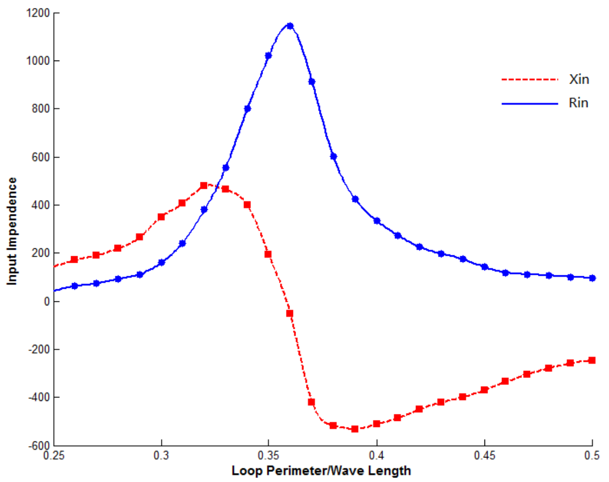

Fig. 2 Simulated input impedance of a nano-loop antenna.

Next, we study the near-field pattern around the nano-loop antenna. Fig. 3 plots the simulated total field intensity in the horizontal plane 10nm above the antenna (*z=30nm*). It is seen that more fields are concentrated in the gap region and distributed along the gold loop. Radiation patterns of the nano-loop antenna are shown in Fig. 4 where two cut-planes (xz and xy planes) are given. It is seen that more radiation occurs in the glass silica region, instead of the air region. This is because the silica can attract more fields due to its higher dielectric constant, as we expect.

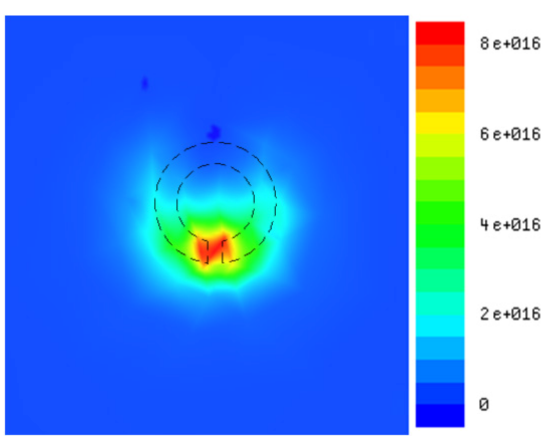

Fig.3. Plot of the total field intensity in the plane 30 nm above the glass surface (*z=30 nm*).

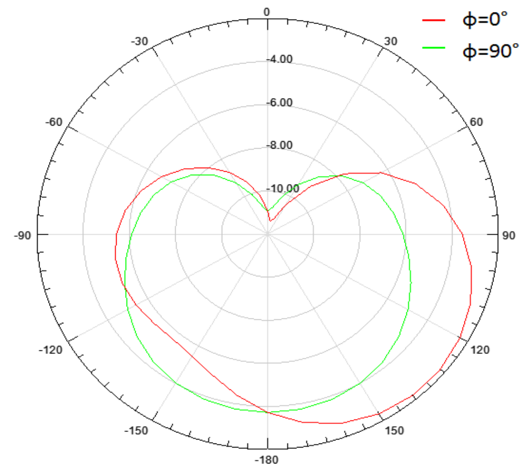

Fig.4. Radiation patterns of the loop antenna in the ϕ= *0°* plane (xz-plane) and ϕ= *90°* plane (yz-plane).

Conclusion

This paper has described a preliminary study of a nano loop antenna operating at the optical frequency. It has been demonstrated that the gold loop antenna resonates when the loop circumference is 0.36 wavelengths, which is in the sub-wavelength scale. By properly selecting the loop dimension and feeding method, one may realize radiation of both linear and circular polarizations.

References

1. Mühlschlegel, P., Eisler, H. –J., Martin, O. J. F., Hecht, B., and Pohl, D. W. Resonant optical antennas. *Science,* **308** (2005) 1607-1609.
2. Novotyny, L. and van Hulst, N. Antennas for light. *Nature Photonics*, 5(2011) 83-90.
3. Biagioni, P., Huang, J. S., Duo, L., Finazzi, M., and Hecht, B. Cross resonant optical antenna. *Phys. Rev. Lett*. **102** (2009) 256801.
4. Şendur, K. and Challener, W. Near-field radiation of bow-tie antennas and apertures at optical frequencies. *Journal of Microscopy*, **210** (2003) 279-283.
5. Taminiau, T. H., Segerink, F. B., and van Hulst, N.F., A monopole antenna at optical frequencies: single-molecule near-field measurements. *IEEE Trans. on Antennas and Propagation,* **55** (2007) 3010-3017.
6. Lerosey, G. Yagi-Uda antenna shines bright. *Nature Photonics*, **4**(2010) 267-268.
7. Hejase, H. A. N. Analysis of a printed wire loop antenna. *IEEE Trans. on Microwave Theory and Techniques,* **42** (1994) 227 – 233.
8. Johnson, P. B. and Christy, R. W. Optical constants of the noble metals. *Phys. Rev.* 6(1972) 4370-4379.