Estimation of Electric Fields at Bow-tie Antenna Gaps

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Localized surface plasmon [1] in metallic nanoparticles coupled to optical excitation tremendously enhances near field intensity. The enhancement of near field brings out many research fields, such as surface plasmon biosensors, nonlinear optics, surface enhanced Raman spectroscopy, etc. Designs of nanoantennas strongly affect the near field intensity. Bow-tie nanoantennas couple well to electromagnetic wave in optical frequency, and create strong intensity in gaps [2].

The bow-tie antennas studied here are composed by two equilateral triangles with 200 nm sides. The gaps range from 20 nm to 60 nm; the thickness of entire structure is 50 nm; the material of antennas is gold; the structures are free of substrate. Based on electrostatic approximation (ESA), eigenvalue problems [3] are solved to find out the resonant modes of bow-tie antennas. Figure 1 is the surface charge distribution of fundamental mode of 40 nm gap bow-tie antenna. Comparing to single triangle structure, the charge is more concentrated to the gap. In other words, the electric field in the gap is enhanced by coupling of triangles. Previously, Mayergoyz et al. [4] calculated the excitation amplitude of resonant mode from the boundary condition. In this work, we proposed the way to find out the excitation amplitude at resonate frequency based on the energy conservation theory. The equation is written as follows:

\[
\left\{ \int E_m \frac{dp}{dt} dv \right\}_r + \int \frac{c \sigma}{6\pi \varepsilon \varepsilon_0} p^2 dv = \left\{ \int E_0 \frac{dp}{dt} dv \right\}_r
\]

The first term is the power dissipation of plasmon mode, \( E_m \) is the electric field produced by plasmon mode. The second term is the radiated power by particles. The term in the right side is the driving power provided by incident wave, \( E_0 \). The dipole moment \( p \) equals \( \varepsilon \times E_0 \). From this equation, once the resonant amplitude is determined, thus the ratio of \( E_m \) and \( E_0 \) is found. Figure 2 shows the parallel component of electric field in the middle of the gap with the gap ranging from 20 nm to 60 nm. Parallel direction means the direction parallel to the gap. The red line is the result of rigorous-coupled wave analysis (RCWA) [5], which serves as the reference. The black and green lines were calculated from our and Mayergoyz’s approach, respectively. We can see that the result of our approach was close to that of RCWA and has greater precision as compared with Mayergoyz’s approach. The prediction of our approach has lower value than the RCWA result.

The near filed plots of electric fields in parallel component with 40 and 60 nm gaps from RCWA simulation are shown in figure 3. There is a maximum in the middle of the 40 nm gap, and the maximum points of 60 nm gap do not locate at the tips of nanoantenna. Figure 4 shows the parallel components of electric field along the connecting line between antenna tips. The results from ESA are regular. Their maximum points are at antenna tips, and the minimum points are at the middle of the gaps. The RCWA profiles distribute as standing waves. We can conclude that there are standing wave oscillations between two tips, and this effect enhances the field intensity in gaps.

By using ESA, we solved the fundamental mode of bow-tie antennas. The amplitudes of the mode were estimated by the energy conservation theory, and were compared to the results of Mayergoyz’s approach. Our approach based on the energy conservation theory shows greater precision. The errors may be caused by the standing wave oscillation between two tips.


Figure 1. The surface charge distribution of the fundamental mode of bow-tie antenna with 40 nm gap.

Figure 2. Simulated parallel component of electric field in the middle of the gap with the gap ranging from 20 nm to 60 nm.

Figure 3. Near field plots of parallel component with 40 and 60 nm gaps from RCWA simulation.

Figure 4. Parallel component of electric fields between gaps.