

# Numerical Simulation of Bull's Eye Grating Using COMSOL Multiphysics® Software

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## Abstract

Plasmonic gratings like bull's eye can localize E field in subwavelength dimensions due to excitation of surface plasmons. Due to this property, when integrated with Ge-on-Si photodetector they can help in fabrication of ultra small photodiodes with high sensitivity and high speed of response [1, 2]. Fig. 1 shows the schematic of bull's eye grating in both top view and cross-sectional view with parameters optimized at 1550 nm. Since bull's eye grating are used to focus light incident on the grating surface, we have numerically carried out a frequency analysis for the same using COMSOL Multiphysics® software with plane wave excitation at normal incidence.

The numerical simulation has been done in 2D axisymmetric model of COMSOL Multiphysics® software. We have used the frequency domain study under the radio frequency module. The 2D axisymmetric model has been chosen to accurately replicate the annular nature of the grating shown in Fig. 1. We have excited the grating with plane wave of the form  $\exp(-izk_z)$  with normal incidence. The model has been assigned an outer layer of perfectly matched layer to minimize reflections. The different parameters of the grating optimized for 1550 nm are written down under definitions node and are used for building the geometry [3]. Fig. 2 shows the model used along with the boundary conditions and the dimensions. The metal used is Aluminium and we assume  $\epsilon(\omega)=1-(\omega_p^2)/(\omega^2+i\gamma\omega)$  where  $\omega_p=2.24 \times 10^{16}$  rad/s is the plasmon frequency and  $\gamma=1.22 \times 10^{14}$  rad/s is the damping co-efficient [5]. We use a physics controlled mesh with maximum element size as  $(2\pi f_0)/5$  where  $f_0$  is the desired frequency.

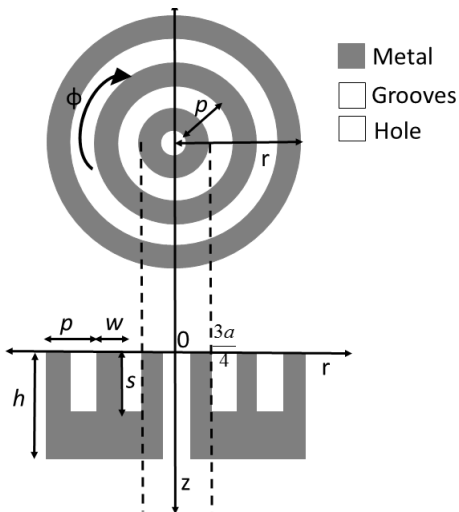
Fig. 3 shows the E field distribution across the bull's eye grating for  $\omega=\omega_p=2.24 \times 10^{16}$  rad/s. We compute the E field from the output of the grating across frequencies below, at and above  $\omega_p$ , by a parametric sweep of  $f_0$ . It can be seen from Fig. 4 that for frequencies below we have peaks of high amplitude with narrow line width due to the presence of localized surface plasmons. The amplitude decreases for frequencies above  $\omega_p$  and the line widths also become broad. This is due to propagating surface plasmons. Thus we have investigated frequency response of the bull's eye grating leading to excitation of surface plasmons at different frequencies.

We have computed a frequency study of the bull's eye grating using Al for  $0.8 < \omega_p < 1.2$ . The enhancement in the E fields due to excitation of surface plasmon polaritons can be seen at specific wavelengths satisfying the grating coupling equation. These grating when integrated with Ge-on-Si photodiodes will enhance responsivity at the computed wavelengths, thus paving the way forward for photodiodes of ultra small active area with high sensitivity and high bandwidth of operation.

## Reference

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- [2] F. F. Ren, K. W. Ang et al, "Split bull's eye shaped aluminum antenna for plasmon enhanced nanometer scale germanium photodetector", Nano Letters, vol. 11, pp. 1289-1293(2011).
- [3] O. Mahboub, S. C. Palacios et al, "Optimization of bull's eye structures for transmission enhancement", Opt. Express, vol. 18, no. 11, pp. 11292-11299(2010).
- [4] L. Feng, M.-H. Lu et al, "Plasmonic photonic crystal with a complete band gap for surface plasmon polariton waves", Applied Physics Letters, vol. 93, (2008).

## Figures used in the abstract



Top view and corresponding cross-sectional view of the bull's eye grating

Figure 1: Top view and corresponding cross-sectional view of the bull's eye grating.

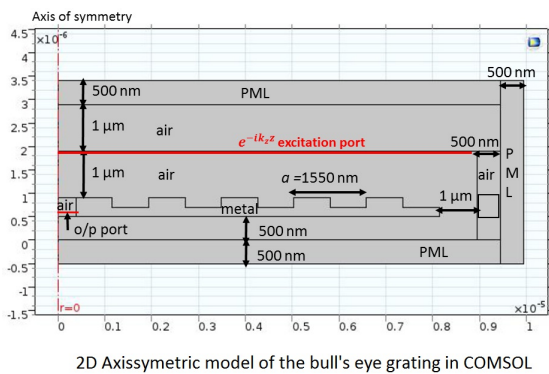


Figure 2: 2D axisymmetric model of the bull's eye grating.

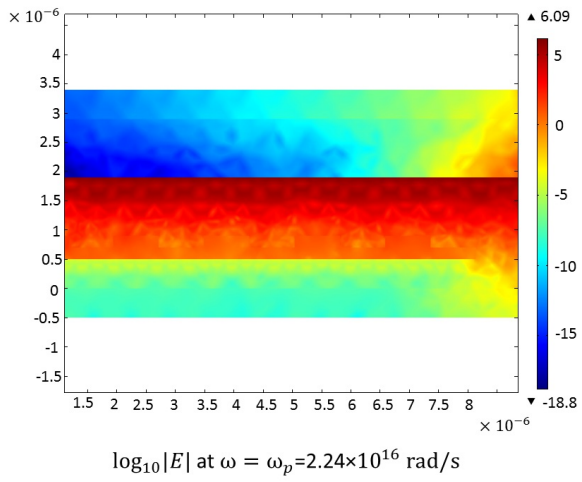


Figure 3:  $\log_{10} |E|$  at  $\omega = \omega_p = 2.24 \times 10^{16}$  rad/s.

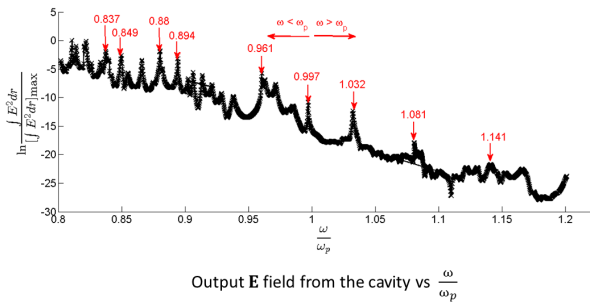


Figure 4: output E field from the cavity vs  $\omega/\omega_p$ .