# Numerical Analysis of Scattering Cross Section of Non-Precious Metallic Plasmonic Nanodisks

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## INTRODUCTION

The recent advancement in plasmonics provided researchers with enormous possibilities. However, the plasmonic materials currently being used are mostly precious metals like gold and silver. In this work, the scattering cross section (SCS) of various sized nanodisks made of three non-precious metals, aluminum, nickel, and copper, are examined and compared to the result of silver. Overall, all three metals show the same red-shifting pattern as the diameter increases. Unlike the Ag nanodisk, which tends to present the highest SCS in the ultraviolet range, Al, Ni, and Cu nanodisks exhibit the constantly high SCS throughout the visible region. Also the amplitudes of the SCS of the Al, Ni, and Cu nanodisks are comparable with the Ag nanodisk in the visible region. These results suggest of the cost effective replacement of precious metals in application of plasmonics-based optics.

## I. THEORY

### A. Drude-Lorentz model

The high reflectivity of light from metals is due to the abundance of free electrons. The collective movement of these free electrons, *plasmons*, responding to eletromagnetic fields, can be fully described by the dielectric function. [1] Since the free electrons play a role as significant as bound electrons, the dielectric function of metals can be described mathematically by

$$\tilde{\epsilon}(\omega) = \tilde{\epsilon}^{(free)}(\omega) + \tilde{\epsilon}^{(bound)}(\omega), \tag{1}$$

where $\tilde{\epsilon}^{(free)}(\omega)$ is the free electron contribution to the dielectric function and $\tilde{\epsilon}^{(bound)}(\omega)$ is the bound-electron contribution. The free electron contribution can be described by Drude model and the bound-electron contribution can be described by Lorentz model. As a result, Equation (1) can be written as

$$\tilde{\epsilon}(\omega) = 1 - \frac{f_0\omega_p^2}{\omega(\omega - i\Gamma_f)} - \sum_{j=1}^{n} \frac{f_j\omega_p^2}{\omega^2 - \omega_j^2 + i\Gamma_{b,j}}, \tag{2}$$

which is referred as Lorentz-Drude model. [2] The parameters of Ag, Al, Ni, and Cu used in this work are taken from reference [2], and are plotted in Figure 1.

### B. Numerical computation of scattering cross section

One of the most interesting quantities regarding the optical response of metals is the scattering cross section (SCS). The SCS is in indicator of how strongly plasmons interact with the incident electromagnetic waves, especially in the visible range. While it is possible to calculate the SCS at each wavelength of electromagnetic waves in the interested range, it is more efficient to apply a Fourier transform on a response spectrum to a short pulse to get the broad range spectra. [3] The scattered power spectrum of an object through a surface that encloses it is given by

$$\begin{aligned} P_{scat}(\omega) = \quad & \mathbb{R} \oint_S \left( [\mathbf{E}_\omega(\mathbf{r}) - \mathbf{E}_{\omega,0}(\mathbf{r})]^* \right. \\ & \left. \times [\mathbf{H}_\omega(\mathbf{r}) - \mathbf{H}_{\omega,0}(\mathbf{r})] \right) \cdot d\mathbf{A} \end{aligned} \tag{3}$$

The SCS, $C_{scat}$, can be obtained by taking the ratio of $P_{scat}(\omega)$ to the incident irradiance, $I_0$:

$$C_{scat} = \frac{P_{scat}(\omega)}{I_0} \tag{4}$$

## DISCUSSION

Overall, all three metals show the same red-shift pattern as the diameter increases. Unlike the Ag nanodisk, which tends to present the highest SCS in the ultraviolet range, Al, Ni, and Cu nanodisks exibit the constantly high SCS throughout the visible region. Also the amplitudes of the SCS of the Al, Ni, and Cu nanodisks

($\approx 2.2 \times 10^4$ atomic unit for 70-nm-diameter nanodisks) are comparable with the Ag nanodisk ($\approx 3 \times 10^4$ atomic unit). These results can lead to a conclusion that non-precious metals such as aluminum, nickel, and copper can be used as an alternative to silver without sacrifying the efficiency in the visible range.

## ACKNOWLEDGEMENT

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## REFERENCES

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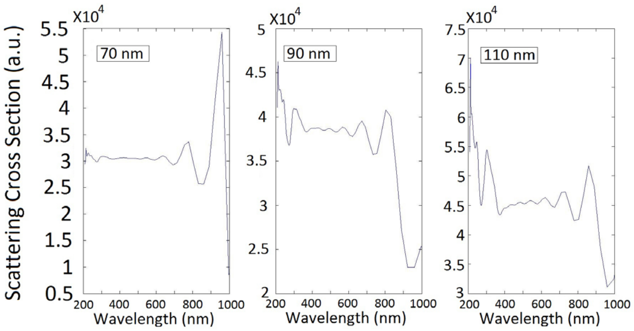
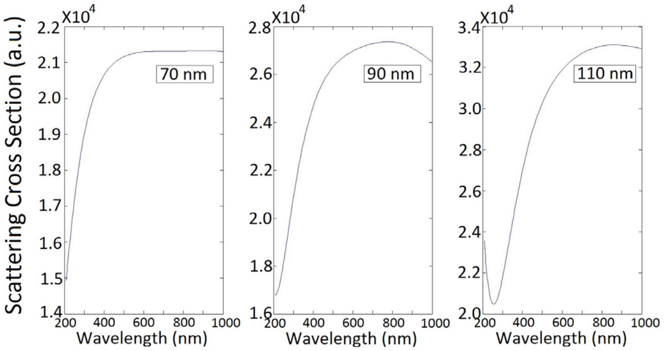
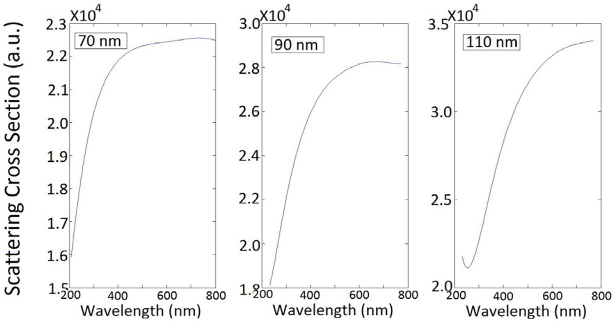


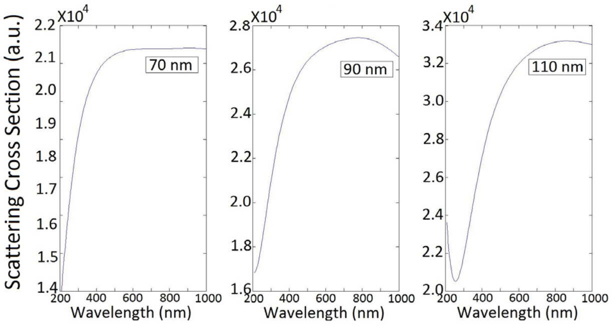
(a) Ag



(b) Al



(c) Cu



(d) Ni

Fig. 1. Scattering cross section as a function of light frequency for (a) Ag, (b) Al, (c) Cu, and (d) Ni nanodisks with diameters of 70 nm, 90 nm, and 110 nm, respectively, from left to right in each material