Tailored focal length of the sub-wavelength slit-groove-based metamaterials in THz regime.

Kwangchil Lee[a], and Kyoungsik Kim[a*]

[a] School of Mechanical Engineering, Yonsei University, 262 Seongsanno, Seodaemun-gu, Seoul 120-749, Republic of Korea

kks@yonsei.ac.kr

***Abstract*—We design the slit-groove-based metamaterials of sub-wavelength resolution and high transmission (~60%) with precisely controllable far-field focal length in the range of λ by modulating the depth of grooves.**

I. Introduction And Background

There have been extensive efforts to research plasmonic metal optics to realize the sub-wavelength resolution and high transmission in the optical region [1,2,3]. In THz frequency regime, which bridges the gap between microwave and the far infrared, the plasmonic THz optics are attractive because of potential applications from high resolution biomedical imaging to security inspection [4,5,6,7]. However, surface plasmons are not inherently generated in THz regime because most metals have high absorption loss and act like perfect electric conductors (PEC) [8]. To overcome this problem, the artificial periodic structures (metamaterials) can be introduced for the THz plasmonic optics to generate the spoof plasmon [9]. These metamaterials are able to realize the far-field focal length, sub-wavelength resolution, and high transmission.

In this report, we studied the tailored focal length of a slit surrounded with grooves [10, 11] depending on the groove depth, using FDTD calculation and Perfect Electric Boundary condition analysis by Hankel's function in THz regime. The focal length of these structures can be adjusted by arranging the depth profile of each groove in defined curvature. These THz lens with tailored focal length are useful for high resolution and transmission for THz imaging.

II. Results

Figure 1 is the geometry we used to calculate the THz slit-groove-based structure. This structured Au coated stainless steel plate plate has PEC-like EM response in the THz region. A P-polarized (x-direction) plane wave is incident in parallel to the grating direction. Each geometrical parameters (groove width, period, depth, and thickness of plate) is optimized by Perfect Electric Boundary condition analysis of Hankel's function based on following equation [3],

$$\left[G_{\alpha\alpha}-\varepsilon_{\alpha}\right]E_{\alpha} + \sum_{\beta\neq\alpha} G_{\alpha\beta}E_{\beta}=2iA_{0}\delta_{\alpha 0} \,. \quad (1)$$

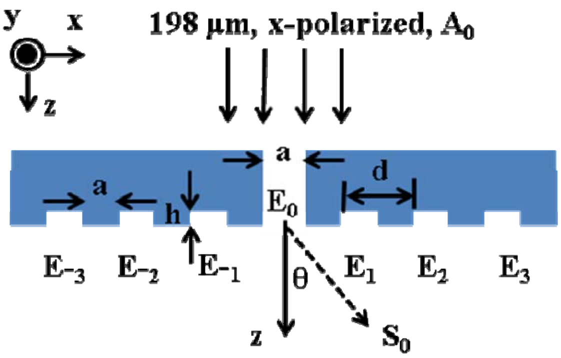
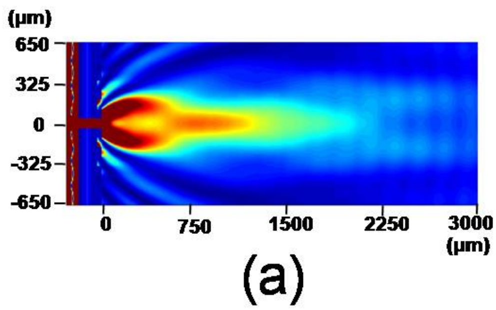


Fig. 1. Geometry of slit-groove-based THz optics. a=66μm, d=150μm, and 180 μm -thick Au coated stainless steel plate.

The tuning range of groove depth is obtained to have directional propagation property. The transmittance of this system and magnetic field are calculated in the z>0 region from Eq. (1) and Eq. (2) as following,

$$H_{y}(\vec{r}) = \frac{1}{\mu_{0}c}\sum_{\alpha} E_{\alpha}G(\alpha,\vec{r}). \quad (2)$$

All other EM field components are calculated from relation of polarization with the H-field.



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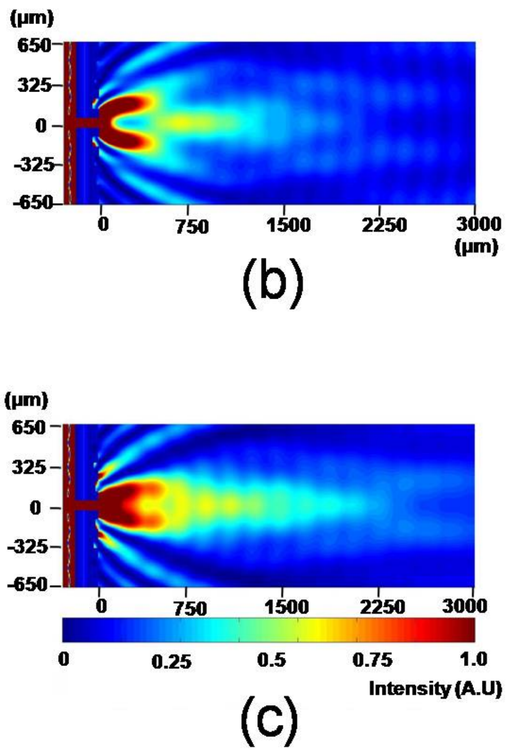

Fig. 2. The predicted relative phase of E_x field by FDTD calculation. The depth of second grove is 30μm. (a) All groove depth is 30μm, which is flat profile. (b) The farther grooves from slit has the swallower profile by 15μm step. (c) The farther grooves from slit has the deeper profile by 15μm step.

From the Periodic Boundary Condition analysis of Hankel's function and FDTD calculation, the relative phase of E_x field scattered by spoof plasmon based on metallic groove can be modulated by controlling the groove depth. When the depths of each groove are arranged in defined curvature like refractive lens, it is possible to precisely modify the focal position in the range of λ without increasing the size of the plasmonic THz optics as shown Figure 2. Especially, the deeper profile of periodic structure as shown Fig. 2(c) has the longest far-field focal length in our calculation. And High transmission (~60%) is also obtained with this metamaterial.

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