

Analyzing Goos-Hänchen Shift on Dielectric Gratings

Products: DiffractMOD RCWA, MOST

Applications: Photonic Sensors and Sensing Applications

When a beam experiences a total internal reflection, a lateral shift exists between the reflected and the incident beams. It is called Goos and Hänchen effect, named after its discoverers. For decades, the phenomenon has been a research topic attracting considerable number of efforts for its intriguing physical nature. It gained renewed attention in recent years when plasmonic materials and metamaterials are involved. Sensor schemes based on GH shift have also been proposed, and have led to sensors of biochemical, thermal and wavelength monitoring applications. The sensitivity in these sensors is directly related to the amount of GH shift, thus, to achieve a large GH shift (positive or negative) is of practical interests.

In the reference paper ¹, the possibility to use the guided mode resonance to achieve giant GH shift was proposed. As shown in Fig.1, the incidence comes from the substrate side of the grating at an angle greater than the critical angle of the substrate and will be totally reflected from the surface of the substrate decorated by the dielectric grating. When the incidence couples to the leaky mode of the grating, strong energy flow inside the waveguide exists, thus giant GH shift could be realized. When the leaky mode is a negative propagating one (i.e. the energy flow is anti-parallel to the wave vector of the mode), negative GH shift is expected.

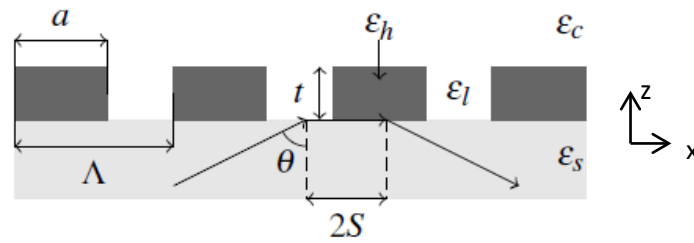


Figure 1. Schematic of a dielectric grating and the GH shift under total internal reflection. The grating specs are $\Gamma = a/\Lambda$ (duty cycle), $\Lambda = 0.43 \mu\text{m}$, $\Gamma = 0.93$, $t = 0.11 \mu\text{m}$, $\epsilon_h = 12.12$, $\epsilon_l = \epsilon_c = 1$ (free space), $\epsilon_s = 2.09$ (SiO₂).

The GH shift is defined as:

$$S = -\frac{1}{k \cos \theta} \frac{d\phi}{d\theta} = -\frac{d\phi}{dk_x}$$

Here θ is the incident angle of a plane wave from substrate side; ϕ is the phase of the reflection coefficient; k is the wavenumber inside the medium of the incident side, while $k_x = k \sin(\theta)$.

To study the GH shift, the incidence is of s polarization with the electric field perpendicular to the plane of incidence. k_0 and k_x are selected that inside the substrate only the 0th order diffraction (the direct reflection) is propagating, while all higher order diffraction modes are evanescent, while in the air both the 0th and higher diffraction orders are evanescent. For $1.5 \mu\text{m}$ free space wavelength of the incidence, this corresponds to k_x between $0.287 \sim 0.414 \times 2\pi/\Lambda$, or θ between $43.8^\circ \sim 90^\circ$. Our RCWA tool, DiffractMOD can be used here to measure the 0th diffraction order phase vs k_x by varying incident angles.

The structure with above grating specs is set up in RSoft CAD, as shown in Figure2. Only one period is needed to be drawn with RCWA simulation.

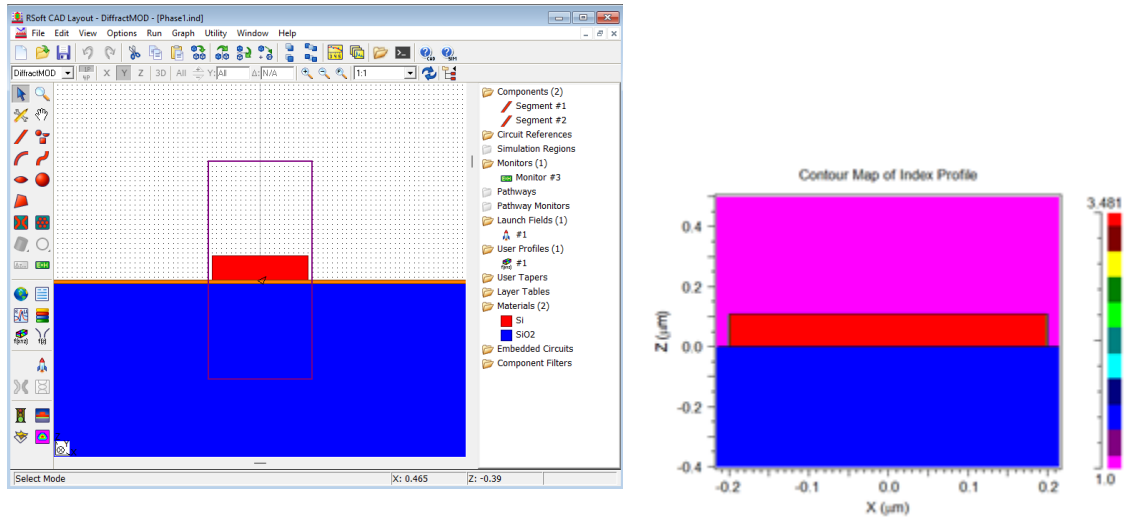


Figure 2. Structure set up in Rsoft CAD and index distribution for one grating period

The whole simulation procedures are:

1. Complex E Field coefficient of reflection for s incident is measured.
2. Scan k_x via changing incident angle with MOST.
3. Define a user measurement to extract the phase of the 0th order from complex field coefficient data file.
4. Unwrap phase data file with python unwrap function.
5. Use "mathmat" utility to form a data file with unitless phase vs k_x .
6. Use "disperse" utility to calculate the first derivative of $-d\phi/dk_x$.

There is a python scripting file included in supporting files which does the operation from 4 to 6 of above procedures after obtaining phase scan output.

The simulation results are shown Figure3. The curve of the reflection coefficient phase exhibits a sharp increase of almost 2π at around $k_x = 0.38 \times 2\pi / \Lambda$, or $\theta = 67.0^\circ$. A sharp dip in the curve of GH shift is observed at the same k_x value when the phase exhibits a steep increase. At its maximum magnitude, the GH shift reaches a value of over $-1000 \mu\text{m}$. Figure 4 shows the electric field and Poynting vector distribution at $k_x = 0.38 \times 2\pi / \Lambda$. At this k_x point, the field goes to $+x$ direction but the energy points to the opposite direction.

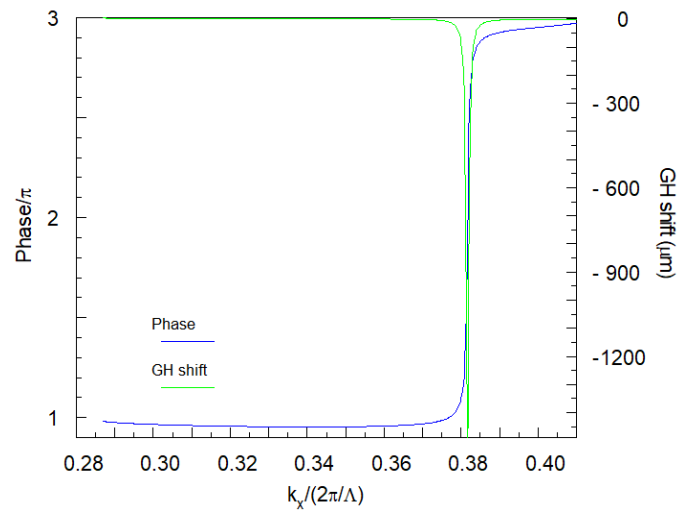


Figure 3. Phase of the reflection coefficient and GH shift vs k_x for an incidence of $1.5 \mu\text{m}$ free space wavelength from the substrate

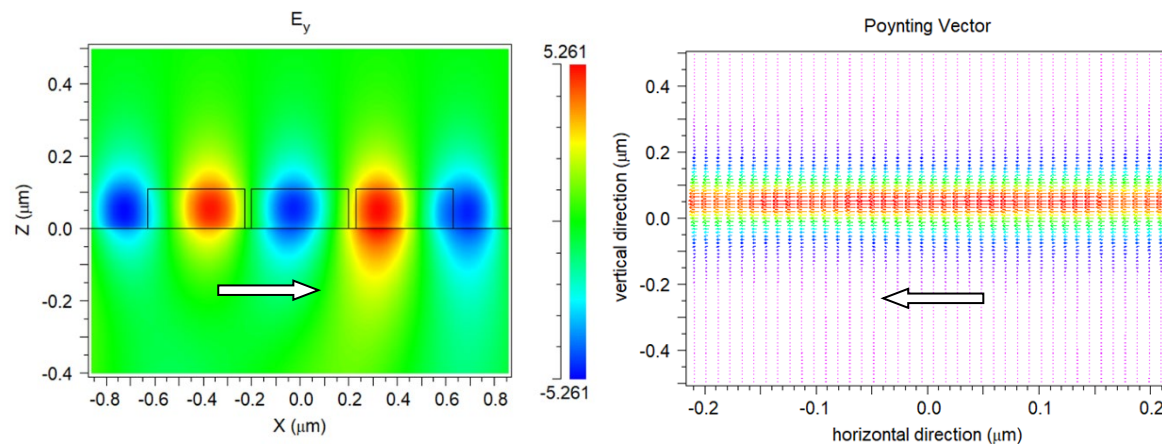


Figure 4. The Instantaneous distribution of electric field E_y and Poynting vector at $k_x = 0.38 \times 2\pi / \Lambda$ (negative GH shift of maximum magnitude)

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