Polarization Property of a Double-layer Wire Grid Polarizer and the Mechanism of Transmission

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Abstract: We fabricated a double-layer wire grid polarizer (WGP) and performed optical characterization to clarify the relationship between structure and polarization characteristics. For normal incidence, the fabricated double-layer WGP exhibits an extinction ratio of 30.4 dB for a period of 400 nm. The transverse magnetic (TM) transmittance peak is found to vary with the period of WGP. The peak shift can be explained on the basis of extreme transmittance phenomena exhibited by the surface plasmon polariton (SPP) of metal slit structures. It is considered that the incident light passes through the resist layer, followed by the excitation of SPP at the interface between the resist and Au. Subsequently, it combines with the transmitted light in the glass substrate, leading to strong transmitted light with TM polarization.

Introduction: The current state-of-the-art system for exposing circuit patterns in a semiconductor device or liquid crystal is by photolithography. To enhance the precision of a semiconductor structure, it is necessary to improve the resolution of the photolithographic system. This often requires a projection system with a light source of a shorter wavelength and large caliber. Besides, the effect of contrast-reducing p-polarized light in the device can be circumvented using s-polarized light. In practice, two types of polarizing elements are used to control the polarization state of a light source, namely, prism type and filter type, of which a wire grid polarizer (WGP) is a filter-type polarizer. This polarizer is considered suitable for use in electron beam lithography.

Given these advantages, in this study, we used a double-layer WGP that uses a double layer of a metal wire to realize a high optical extinction ratio when compared with the conventional WGP. Furthermore, the double-layer WGP offers the advantage of simplifying the fabrication by skipping the process of removing the resist. Besides, the simulation of polarization over the horizontal interval of the distance or a metal small-gage wire is conducted for two layers[1, 2]. However, to the best of our knowledge, there are no experimental studies reported so far on the double-layer WGP. In this study, we attempted to clarify the relationship between the structure and polarization property of a double-layer WGP and investigate the various parameters, such as period and metallic film thickness, to obtain an optimum structure.

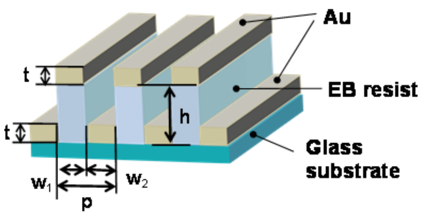

Fig. 1: Schematic diagram of WGP.

Experiments Procedure: Fig. 1 shows the schematic of the WGP made on a glass substrate using electron beam lithography system (CABL-8000, CRESTEC). The double-layer WGP was fabricated by sputtering a Au layer (SC-701MC, SANYU). Polarization measurements were performed using a red laser of wavelength λ = 635 nm. The polarization property of the fabricated double-layer WGP was characterized for different periods by varying the incident angle from 0 degree to 70 degree.

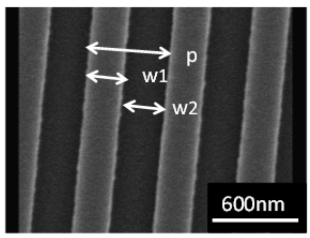

Fig. 2: Surface SEM image of WGP. p = 600 nm, w_1 = w_2 = 300

Experimental Results and Discussion: Fig. 2 shows the surface morphology of the double-layer WGP, as observed using SEM. As is seen, the WGP has almost the same structures.

Furthermore, we evaluated the polarization property of the fabricated double-layer WGP. Fig. 3 shows the TE and TM transmittance spectra of normal incidence for various periods.

The highest transmittance of TM polarization is obtained for a period of 400 nm. On the other hand, the transmittance of TE polarization is about 1000 times smaller than that of TM polarization. The extinction ratio for the 400-nm-period is 30.4 dB, which is almost similar to that of the commercial products. Subsequently, we characterized the dependence of TM transmittance on the incident angle. Fig. 4 shows the relationship between the period and incident angle, corresponding to the peak of TM transmittance. The peak angle is varied with the period.

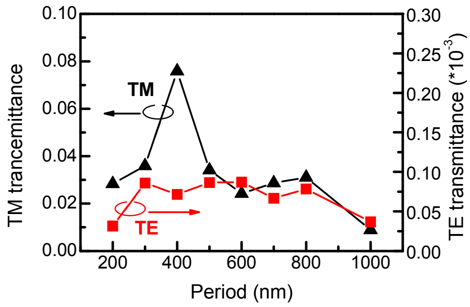

Fig. 3: TE and TM transmittance of normal incidence for various periods.

Furthermore, to consider the peak shift of the incident angle, we speculated the extreme transmission phenomena by surface plasmon[4]. For the simplified model composed of Au grating and a dielectric medium of refractive index 1.25, average of air and the resist, the dispersion relationship of surface plasmon polariton (SPP) and the incident angle excites the SPP. Fig. 5 shows the relationship between period and incident angle, which shows a peak corresponding to the TM transmittance of experimental data and calculated data. The calculated data are almost identical to the experimental data. Furthermore, the distribution of electrical field is calculated by the rigorous coupled wave analysis method. Fig. 6 shows the distribution of electrical field for a period of 316 nm and an incidence angle of 30 degree. The electrical field is concentrated at the interface of Au and the resist in the vicinity of the glass substrate. It is considered that the incident light passes through the resist layer, followed by the excitation of SPP at the interface between the resist and Au. Subsequently, it combines with the transmitted light in the glass substrate. This results in strong transmitted light with TM polarization.

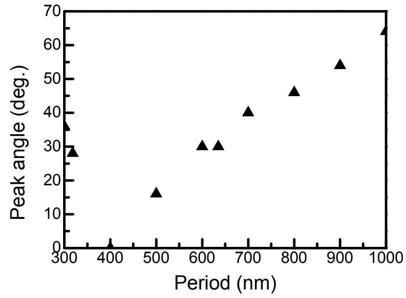

Fig. 4: Relationship between period and incident angle showing peak corresponding to TM transmittance.

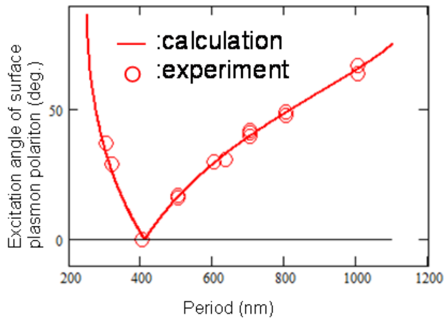

Fig. 5: Relationship between period and incident angle showing peak corresponding to TM transmittance of experimental and calculated data.

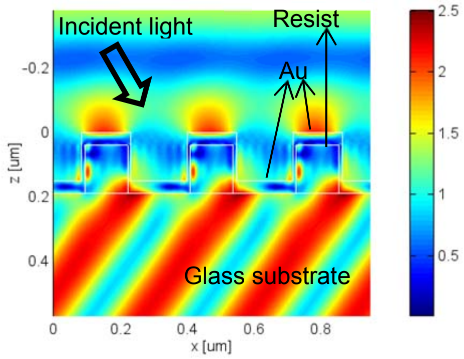

Fig. 6: Distribution of electrical field for a period of 316 nm and an incidence angle of 30 degree.

Conclusion: In summary, we clarified the relation between structure and polarization property in double-layer WGP to obtain the optimal structure. The polarization property of the fabricated double-layer WGP for the different period was characterized with the incident angle varying from 0 degree to 70 degree. The peak incident angle of TM transmittance is found to vary as a function of the period. This can be explained on the basis of the extreme transmission phenomena by surface plasmons.

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References

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