Design of transverse magnetic-reflected polarizing film

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We propose a wideband transverse magnetic-reflected polarizing film composed of Cr and SiO_2. Based on the polarization characteristics of reflected light from Cr/SiO_2 film, the film can serves as a polarizer to severely attenuate the transverse electric (TE)-polarized light and reflect the transverse magnetic (TM)-polarized light in a wavelength range from 600 to 900 nm. By suitably choosing the film thicknesses, the operation angles of such polarizers can be adjusted over a wide angle range greater than the critical angle of total reflection. Cr/SiO_2 film has potential use in surface plasmon resonance (SPR) sensors based on Kretchmann configuration to form integrated structures.

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Surface plasmon is a surface wave that resulting from the coupling of electromagnetic waves and free electrons in a metal. It has attracted a surge of interest in recent years for its unique properties and its great potential for practical applications[1−3]. To excite surface plasmon waves (SPWs) more efficiently and get more obvious phenomenon of surface plasmon resonance (SPR), transverse magnetic (TM)-polarized lights are desired instead of transverse electric (TE)-polarized lights, thus, the utilization of polarizer is necessary.Many kinds of polarizer with high extinction ratio and low insertion loss have been developed using various techniques, e.g., micro-and nanostructure polarizers[4−7], Brewster angle film polarizers[8,9], in-line fiber-optic and waveguide polarizers[10−12]. Nevertheless, in conventional Kretchmann configuration, birefringent prisms and multi layer dielectric polarizing beam splitters (PBS) are more frequently used and installed separately from the coupling prism. The former rely on the natural birefringence of crystal materials, while the latter are based on light interference effects[13]. These polarizers suffer from common disadvantages such as high cost, complex fabrication techniques and difficult to be incorporated as integrated components.

A miniature polarizer has already been incorporated into SPR scheme for angular modulation to form a highly compact structure[14]. However, in the case of wavelength modulation, a miniature polarizer should be wide band, thus, a compromise between its dimension and bandwidth need to be take into account, as well as the cost. To integrate with a coupling prism, a polarizing film based on Kretchmann configuration which can sufficiently reflects TM-polarized light and severely attenuates TE-polarized light may be an alternative.Such polarizing film can be compatible with Kretchmann configuration and easily integrated into the configuration to serve as a polarizer providing TM-polarized light.

In this letter, our aim is to design a wide band TM-reflected polarizing film which could be used as a polarizer in Kretchmann configuration for wavelength modulation. For this purpose, the polarizing film should have following characteristics: sufficient spectral range, tolerable extinction ratio, simple structure, TM-polarized light output and adjustable operation angle.

Several transition metals have large imaginary part of dielectric constants[15]. Among them, vanadium (V) and chromium (Cr) has small magnitude of real part of dielectric constants.Cr has strong adhesion to dielectric surface and has been used in in-line fiber-optic[16−18] and waveguide polarizers[19−21]. In this work, we choose Cr/SiO_2 film to design a wideband TM-reflected polarizing film. To investigate the effect of Cr/SiO_2 film on the polarization characteristics of reflected light, the reflection spectrums of Cr/SiO_2 film for TM- and TE-polarized lights are obtained by using Fresnel's equations of the prism/film/air layer system. More details about the reflection of multiple beam interference are elaborated in Ref. [22]. The schematic of four layer structure

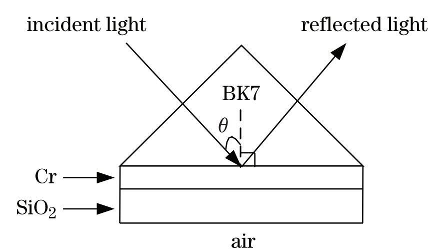

Fig. 1. Schematic of four layer structure: BK7 prism/Cr/SiO_2/air. θ is the value of incident angle.

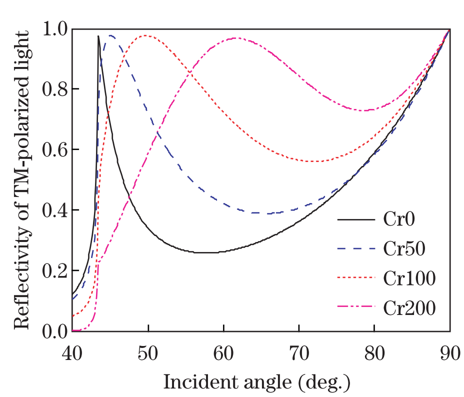

Fig. 2. (Color online) Angular reflectivity of TM-polarized lights at 750-nm wavelength.

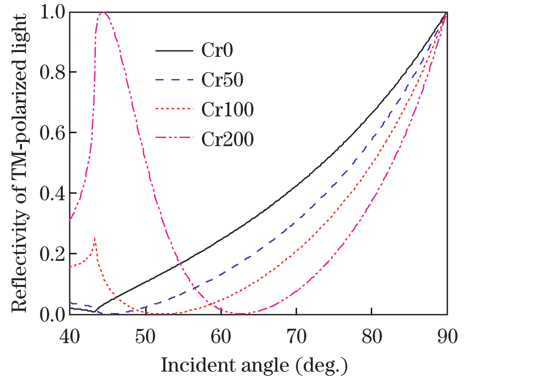

Fig. 3. (Color online) Angular reflectivity of TE-polarized lights at 750-nm wavelength.

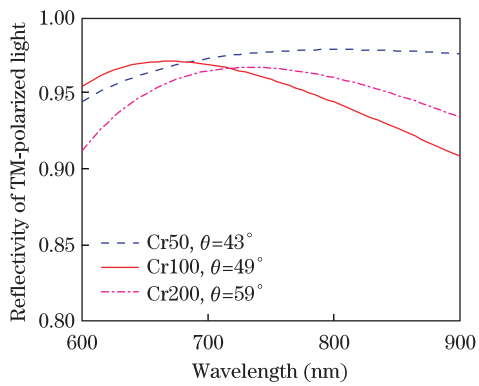

Fig. 4. (Color online) Spectral reflectivity of TM-polarized lights.

is illustrated in Fig. 1. The reflection and refraction caused by the prism are not taken into consideration in theoretical analysis. The simulation is performed using a LabVIEW/MATLAB program.

Figures 2 and 3 show the angular reflectivity of TM-and TE-polarized lights at 750-nm wavelength for Cr/SiO_2 films with different film thicknesses: 6-nm Cr, 6-nm Cr/50-nm SiO_2, 5-nm Cr/100-nm SiO_2, and 4-nm Cr/200-nm SiO_2. For simplicity, the films are denoted as Cr0, Cr50, Cr100, and Cr200, respectively. For Cr0, it is observed that reflection of TM-polarized light appears a sharp peak, whereas TE-polarized light shows quite low reflectivity in total reflection region mainly due to the large imaginary part of dielectric constants of Cr which represent the absorption.The imaginary part of dielectric constants of Cr affects both the peak of TM-polarized light and dip of TE-polarized light according to the multiple beam interference. However, the electrical filed of TM-polarized light is strongly confined in Cr film with finite thickness, while the electrical filed of TE-polarized light is not restricted in the direction perpendicular to the plane of incidence, making the TE-polarized light more lossy than TM-polarized light. In addition, as the thickness of SiO_2 film increases, broad dips emerge for TE-polarized light and the peaks for TM-polarized light become broad. Meanwhile, the peaks and dips shift toward larger angles. Further analysis show that owing to the small magnitude of real part of dielectric constants of Cr, the peaks and dips appear at similar incident angles and can be tuned easily by changing the thickness of Cr film to obtain higher ratio between reflectivity of TM- and TE-polarized light.

The principle of interference provides a simple way for interpretation of the phenomenon. For TE-polarized light, instead of TM-polarized light, destructive interference occurs due to multiple beam interference caused by the film at an appropriate incident angle. Because of the dispersion effects of prism and film, the peaks of TM reflectivity and dips of TE reflectivity vary with different incident wavelengths. However, their positions and shapes are not significantly changed in a certain range of wavelengths, which provide the possibility of designing a wideband TM-reflected polarizing film.

We theoretically investigated the spectral reflectivity of TM- and TE-polarized lights at several given incident angles for Cr50, Cr100, and Cr200. As shown in Figs. 4 and 5, TE-polarized lights are severely attenuated over a wavelength range of 600−900 nm after being reflected by the films, while TM-polarized lights remain relative high reflection. For both TM- and TE-polarized lights, the reflectivityis dependent on the incident angle, especially for TM-polarized lights, which has a large impact upon the performance of polarizing film: the extinction ratio and power loss. Fortunately, not only we can choose an incident angle as an operation angle to optimize the performance of a fixed polarizing film, but also the operation angle can be adjusted over a wide angle range by suitably choosing the film thicknesses, which could brings great convenience to integrate the polarizing film with a coupling prism to form a compact Kretchmann configuration. In the simulations, the dielectric constants of Cr and SiO_2 are sourced from Refs. [15,23], respectively.

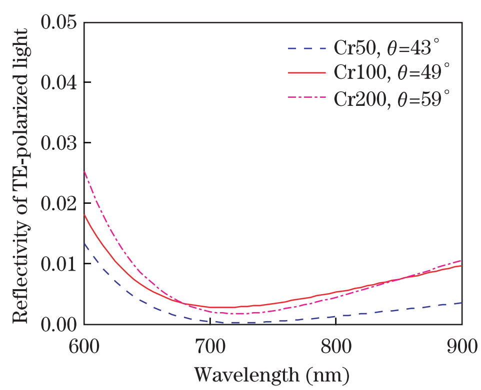

Fig. 5. (Color online) Spectral reflectivity of TE-polarized lights.

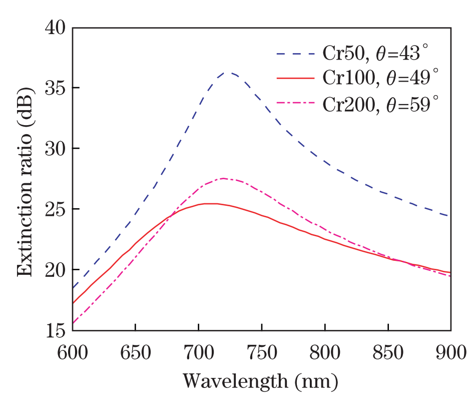

Fig. 6. (Color online) Extinction ratio for TM-polarized lights.

The extinction ratio was calculated from the theoretical spectrums, and the results are shown in Fig. 6. Because the TE-polarized components of light are not eliminated thoroughly and power loss of TM-polarized components, compared with bulk commercial polarizers, the polarizing films we designed show higher loss and lower extinction ratio for TM-polarized light. However, their performances become tolerable when they are used as a polarizer for SPR wavelength modulation, the reasons are as follows: on one hand, an optical spectrometer is commonly used in SPR wavelength interrogation devices, whose integral time is adjustable; on the other hand, the polarizing films with such extinction ratio are enough to improve the coupling efficiency between light waves and SPWs.

In conclusion, we design a wideband TM-reflected polarizing film utilizing the polarization characteristics of reflected light from Cr/SiO_2 film in a wavelength range from 600 to 900 nm. The polarizing film is compatible with Kretchmann configuration, and its operation angle can be adjusted over a wide angle range greater than the critical angle of total reflection.Moreover, due to the materials are not expensive, the polarizing film can be very cheap. As a result, Cr/SiO_2 film has potential use in surface plasmon resonance sensors based on Kretchmann configuration to form integrated structures with low cost.Further, materials like Cr whose magnitude of imaginary part of the dielectric constant much larger than the real part may be potential candidates for use in such polarizing structure.

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