Surface Plasmon Holography for Security Application

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***Abstract*—Holographic technique making use of the concept of surface plasmon excitation can be called as surface plasmon holography. Surface plasmon holography technique can improve diffraction efficiency of hologram and based on it color hologram can be created. Surface Plasmon Resonance is the collective oscillation of electrons on a metal surface. A light beam incident on the SPR hologram will couple with the surface plasmon polaritons, if they match the light momentum, thus the diffraction efficiency is increased by the strong resonance. Normally, a prism or a grating is needed to excite SPR.**

I. INTRODUCTION

A hologram is a complex surface pattern created from interference between a reference wave front and a wave front reflected by an object. The unique feature of holography is the recording of complete wave field, that is, both amplitude and the phase of the light waves scattered by the object. Optical security is a promising technology and widely used due to their parallel and high speed processing capabilities. Holograms were widely used as one of the most trusted tools for product authentication and document security. Holographic storage offers higher data density, faster transfer rates and better safety of stored data.

The quanta of waves are produced by collective effects of large number of electrons in matter when the electrons are disturbed from equilibrium. In other word, the quantum of Plasma Oscillation is called Plasmon. Metals provide the best evidence of plasmons, because they have a high density of electrons free to move. Surface plasmons are those plasmons that are confined to surfaces and that interact strongly with light resulting in a polariton. Surface plasmons, also known as surface plasmon polaritons, (coupling between photon and an excitation of a material) and are surface electromagnetic waves that propagate parallel along a metal/dielectric interface. For surface plasmons to exist, the complex dielectric constants of the two media must be of opposite sign. This condition is met in the IR-visible wavelength region for air/metal and water/metal interfaces (where the real dielectric constant of a metal is negative and that of air or water is positive). Typical metals that support surface plasmons are silver and gold, but metals such as copper, titanium, or chromium can also support surface plasmon generation. When a particular type of light (from the light source) strikes the metals, surface plasmon waves (SPW) are generated at the interface between the conductive metal and the dielectric layer. In addition to the generation of the SPWs, light is also reflected off of the metal surface. At TIR, all the energy from the incident light wave will be transferred to the reflected light wave. However, at a particular angle past the point of TIR, which results in the SPR angle, a majority of the incidence light energy will interact with the generated SPW's. This result in a phenomenon called resonance. The SPR angle is dependent upon several factors, including properties of the metal film, wavelength of the incident light and refractive index of the media on either side of the metal film.

The combination of holography and SPR has been reported to improve diffraction efficiency of hologram and based on it color hologram was also demonstrated. Holographic images were created with high contrast and low noise by the enhancement of surface plasmon wave guiding effect.

II. BASIC PRINCIPLE

The recording process of the Surface plasmon hologram is similar to the conventional hologram recording process. The recording medium we use here is Photoresist material. The interference patterns are formed between a light field coming from the object as scattered light and the unscattered reference beam.The photoresist is a class of Photo-sensitive material that produces imaged relief patterns. Upon exposure to actinic radiation they produce chemical changes in the photoresist layer that enable a solvency differentiation as a function of exposure. Development with suitable solvent promotes dissolution of either exposed or unexposed region depending on the type of photoresist- negative or positive.

After the recording of the hologram on to the photoresist the primary hologram is coated with very thin layer of Aluminum (or gold, silver, chromium) to convert it to a surface plasmon hologram.

For image reconstruction, the SPP is excited by a colour component of white light that is incident on the metal film through a prism with an angle satisfying the condition of total internal reflection. The SPP associates with a non radiative evanescent light wave on metal film and then is converted by the grating component of hologram into a radiative light field, which represents the reconstructed wavefront of light that scattered at the object.

The reconstruction of the prerecorded object is seen with the eyes through an SPP hologram in colour. The reference beam or the zeroth order diffraction as background beam does not exist in reconstruction for this configuration because the illumination of the hologram is made by total internal reflection.

III EXPERIMENTAL SETUP

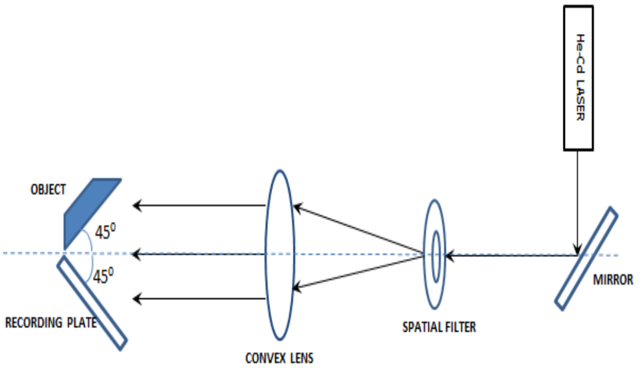

Figure 1. Optical system for recording a transmission hologram: A plane wave is incident at angle of 45°. The object to be recorded is close to the recording plate to alleviate phase difference blur.

The recording setup is similar to a transmission hologram recording setup. Figure 1 shows the optical setup for recording of the hologram. The laser we used is continuous wave He Cd laser of wavelength 441.6nm. It is a metal vapour laser with power output in the range of 120mW. The beam from the laser is spatially filtered to obtain a uniform profile light beam by avoiding random fluctuations. The light beam from the spatial filter is collimated before incident on to the plate and object. The beam is split into two parts after expansion; one (the reference beam) is directly illuminating the recording plate and the other is reflected from the object and then recorded. The incident angle to the plate is 45^0. The intensity after expansion and the exposure time are 4mW/cm2 and 10seconds, respectively. The exposed photoresist is developed with Resist developer or NaOH for 10 seconds. Then, the hologram is rinsed with running water and heated by hot wind for 20s and 30s, respectively. Subsequently, a 40nm aluminum film is deposited onto the hologram.

For reconstruction, one can use both the original reference laser beam and white beam to obtain the image. The image color depends on the color of the laser used to make the hologram, so the reconstruction image is blue due to 457.8nm laser beam. In our experiment, white light is also used to illuminate the plasmonic hologram to achieve the monochromatic holographic images. For reconstruction we use the Kretschmann configuration to excite surface plasmons. The set up consists of a white light source, 100 W halogen lamp. The white light is illuminated on the hologram through prism at a particular angle to excite surface plasmon polaritons. Individual colors are reconstructed by illumination at corresponding incident angles by satisfying the above relationship for each color. The wavelength of the reconstruction light as a function of the incident angle of illumination (excitation) can be given by the relationship as

$$\theta = \sin^{-1}\left(\frac{1}{n_{glass}}\sqrt{\frac{n_m^2 n(\lambda)^2}{n_m^2 + n(\lambda)^2}}\right) \qquad (1)$$

Where, n_{glass}, n_m, and $n(\lambda)$ are the refractive index of the glass substrate, effective index of the medium on the metal surface, and the index of metal respectively.

IV RESULTS AND DISCUSSION

The optical setup for recording the surface plasmon hologram is done and we recorded the image with Helium Cadmium laser on the photoresist material precoated over a glass plate. We also recorded ordinary transmission hologram. The reconstruction of the surface plasmon hologram is done using prism arranged in the Kretschmann configuration.

In the measurement, we compare the image quality and diffraction efficiency of the plasmonic hologram with ordinary one.

Figure 2. Recording setup

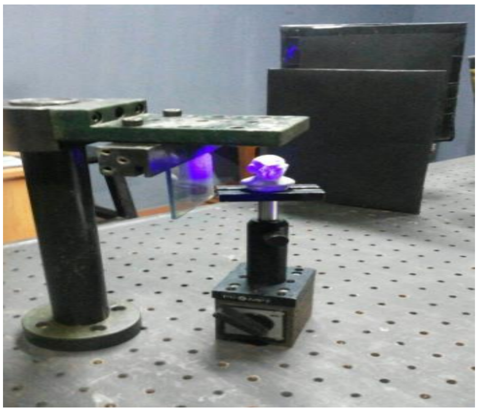

Figure 3. A plane wave is incident at angle of 45°on to the plate as well as object.

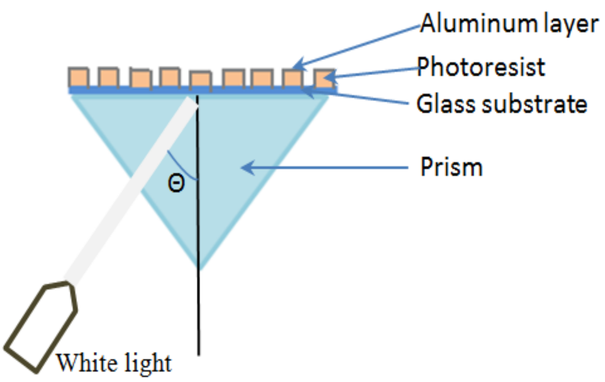

Figure 4. White light reconstruction of SPP hologram

This holography technique finds application in display holography with much better image quality. SPP holography is capable of enabling high-efficiency and high-contrast holograms. The rainbow holograms mounted, also reconstruct with white light, where color varies with viewing angle but not with the color distribution in the object. Plasmon holography is advantageous in terms of background-beam–free reconstruction because the illumination light is totally reflected back at the hologram. These holograms are free from diffraction of light due to background light as the reconstruction is based on excitation of surface plasmon polaritons.

The surface plasmon holograms can open a door for document security. Embossing and metallization are used as countermeasure to protect the holograms from being counterfeited. In SPP hologram we have a metal layer deposited over the photoresist hologram, which provides security to the hologram from being directly copied. The master hologram can be provided with further security by using a specific composition of the metallization or by using variable thickness to metal layer.

V CONCLUSION

In summary, the plasmonic hologram was fabricated and images with individual color (R/G/B) were observed. It was demonstrated that plasmonic hologram significantly enhanced the diffraction efficiency compared to ordinary holograms. The various security aspects that can be utilized in this technique were also studied and analysed. Future work on this holography technique can be done to develop and utilize SPP holograms in various dimension including display holography, document security, product authentication.

VI REFERENCES

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