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Surface Plasmon Polaritons and Visible Radiation Coupling in Dye Doped Liquid Crystal Cells with ZnSe Interlayers

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Abstract: Surface plasmon polaritons excited in PM-597 doped 5CB liquid crystal cells sandwiched with ZnSe coated ITO glass plates proved to be responsible for several intriguing observations we made. Tentative physical picture of SPPs mediation based on electrostatic modification was proposed in this study.
OCIS codes: (240.6680) Surface plasmons; (160.5320) Photorefractive materials; (160.3710) Liquid crystals.

1. Introduction

As promising holographic recording material, liquid crystal (LC) nonlinear optical materials have been studied for many years [1]. With photoconductor interlayers adding to LC cells, the response time were reduced to few to tens millisecond [2]. By applying an external electric field, the surface layer of the photoconductor can be flooded by charge carriers, which will greatly increase the conductivity and hence plasma frequency of the photoconductor by electrostatic modification [3]. In layered structure of plasmonic and nonlinear optical materials, SPPs excitation and energy coupling between light radiation and SPPs can be mediated by phase gratings [4]. By using well conductive n-type semiconductors, the huge loss in metallic materials will be greatly reduced. Several interesting phenomena in dye (PM-597) doped 4,4'-n-pentyl-cyanobiphenyl LC cells fabricated with n-type semiconductor ZnSe coated ITO glass plates were demonstrate in this paper. A tentative physical model was proposed to explain these phenomena which proved to be caused by the coupling between SPPs and visible radiation. This study could serve as guidance in designing tunable, low-loss plasmonic systems and it is also of significance for nonlinear optics research.

2. Experimental and discussion

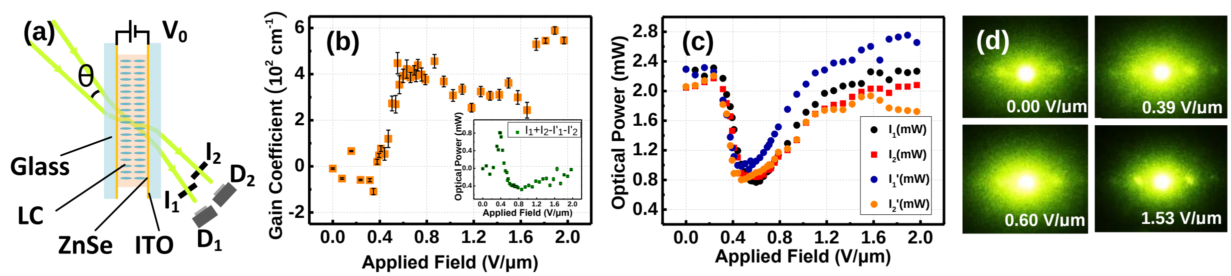

Fig. 1(a) Schematic diagram for two wave mixing (TWM) experiment with asymmetrical incident beams: D_i are detectors, I_i irises with 2.0 mm diameters, θ external cross angle between two beams, and V_0 applied voltage; (b) The TWM gain coefficient versus applied electric field; (c) Transmitted powers with/without two beam coupling; (d) The scattering pattern variation of individual beam at different applied field intensities.

The structure of LC cell and the experimental configuration of TWM experiment are illustrated in Fig. 1(a). We directly deposited 500 nm ZnSe film on top of ITO glass plates using e-beam evaporation deposition, then fabricated a 6.35μm thick, 1.0 wt% PM-597 doped homeotropical LC cell. Two 5 mW p-polarized coherent continuous laser at 561 nm was used throughout the work. The LC cell was titled at angle 45° to the bisector of two writing beams and the crossing angle of two beams was set at θ=1.0°, with the corresponding grating spacing Λ=18.7 μm.

With electric field applied, transmitted powers of two beams were measured at three conditions (see Fig.1(c)): (1) beam 1 alone (marked with I_1); (2) beam 2 alone (I_2); and (3) two beams coexistence (I_1' and I_2'). The gain coefficients were calculated according to $\Gamma=1/[d\cos(\theta/2)]\ln[(I_2 I_1')/(I_1 I_2')]$ and plotted in Fig. 1(b). Without the irises, four selected photographs taken at different electric fields are exhibited in Fig. 1(d). The difference between total transmitted powers of two beams with and without coupling is shown in the inset of Fig. 1(b).

The big error bar and notable fluctuation of gain coefficient in Fig. 1(a) indicate strong dynamic coupling of two beams. From Fig. 1(b-c) one can see that the transmitted light experienced a scattering enhancement and weakening process with the applied voltage increases monotonically. This scattering's up- and down-turns imply at least two competing driving forces in determining the scattering. Obviously, photorefractive effects is one of the driving force which tends to increase scattering powers and distribution angles when the applied electric field was increased. To identify the second driving force, the current and charge accumulation dynamics during switching of electric field/light were taken in the TWM experiment (Fig. 2(a-b)). One thing should be mentioned is that the dark charge accumulation and dark current were attributed to the entire electrode area of the LC cell (12 $\times$ 24 mm^2), whereas only a very small portion of the electrode (4 mm^2) was illuminated which contributed to the photocharge accumulation and photocurrent. Considering the area ratio, the photoinduced contributions were indeed great.

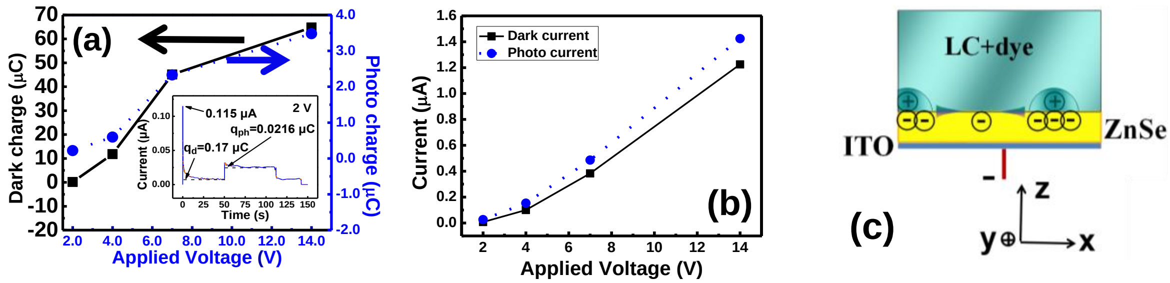

Fig. 2(a) Total charge accumulation near ZnSe/LC interface in dark condition and extra charge accumulation under illumination of laser beam; (b) Stable dark and photo current versus applied voltage. The lines serve as guide for eye; (c) Schematic diagram illustrating carrier charge accumulation and excitation of SPPs near ZnSe/LC interface.

While external field was applied on an LC cell, charge carriers were accumulated on the electrodes. When a ZnSe/LC interface was flooded with electrons, the effective electron density of the skin layer of ZnSe thin film will altered significantly due to electrostatic modulation. In view of plasmonics, the plasma frequency ω_p of ZnSe layer could be shifted greatly towards short wave, since ω_p is proportional to the square root of electron density[4]. From Fig. 2(a), it is seen that 0.17 to 64 μC electrons can be accumulated near the ZnSe/LC interface. Assuming the accumulated electrons were mostly squeezed into a very thin ZnSe layer adjacent to the LC, the plasma response of the ZnSe was able to be shifted into visible region. Therefore, mediated by the gratings written in the LC cells, SPPs can be excited near ZnSe/LC interface on the cathode side. Because of the high sensitivity of photorefractive effect, the weak scattering light in LC cells can be amplified by writing myriad gratings. Consequently, those phase gratings will diffract incident light into various high orders. These phase gratings can also supply quasi-wavevectors of $m(2\pi/\Lambda)$ to the x-component of the incident light wavevector to satisfy phase match condition, The energy of incident light is transferred to the SPPs by diffraction. The vector of SPPs is determined by both dielectric function of the electrostatically modified photoconductor ZnSe and dielectric constant of the LC layer, and the order number m could be either positive or negative. As illustrated in Fig 2. (c), the SPPs propagate in both positive and negative directions of the x-axis. The plasmonic band structure in the ZnSe/LC system was computed by schematically setting Λ=18.7 μm. The manifold dispersion curves fall within the radiation region between the two air light lines, implying coupling between SPPs and light radiation are of two-way process, the scattered beams which form small angles with the incident light write gratings with large spacing period Λ, and hence more dispersion curves are packed between the two light lines. Therefore, scattering with relatively small angles with the incident beam have greater chances to be amplified via backward coupling from SPPs to radiation. This is believed to be the second driving force which brings scattering light back to the incident light direction, while higher electric field pushing plasma frequency toward shorter waves.

3. Conclusion

In conclusion, SPPs excitation was evidenced in dye doped 5CB LC cells sandwiched with ZnSe coated ITO glass plates and great impact on the photorefractive effect was analyzed and verified by experiments. The charge accumulation near the ZnSe/LC interfaces results in electrostatic modification of the plasma frequency toward visible radiation. This findings could be helpful for designing low loss SPPs based devices and in designing fast response, low voltage operated holographic display. Since the charge accumulation is highly electric field and illumination dependent, the electrostatic modification approach opens a new way of exciting SPPs in a tunable way. This methodology itself is significant for plasmonics.

4. References

[1] O. Ostroverkhova and W. E. Moerner, "Organic photorefractives: mechanisms, materials and applications," Chem. Rev. 104, 3267-3314 (2004).

[2] H. Zhao, C. Lian, X. Sun, and J. W. Zhang, "The nanoscale interlayer that raises response rate in photorefractive liquid crystal polymer composites," Opt. Express, **19**, 12496-12502 (2011).

[3] C. H. Ahn, A. Bhattacharya, M. Di Ventra, J. N. Eckstein, C. D. Frisbie, M. E. Gershenson, A. M. Goldman, I. H. Inoue, J. Mannhart, A. J. Millis, A. F. Morpurgo, D. Natelson, and J. –M. Triscone, "Electrostatic modification of novel materials," Rev. Mod. Phys. 78, 1185-1212 (2006).

[4] S. Hayashi, and T. Okamoto, "Plasmonics: visit the past to know the future," J. Phys. D: Appl. Phys. 45, 433001 (2012).