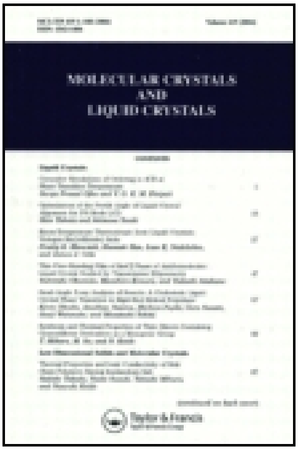

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Optically Addressed Spatial Light Modulator with Highly Sensitive Layer of Amorphous Hydrogenated Silicon Carbide

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OPTICALLY ADDRESSED SPATIAL LIGHT MODULATOR WITH HIGHLY SENSITIVE LAYER OF AMORPHOUS HYDROGENATED SILICON CARBIDE

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Abstract The photoaddressed spatial light modulator (PLSM) with thin hydrogenated amorphous silicon carbide photoreceptor α-$Si_{1-x}C_x$:H and nematic liquid crystal has been fabricated. The films were prepared by rf plasma decomposition of SiH_4 and CH_4 gas mixture. They have a high dark resistivity and photosensitivity as a hydrogenated amorphous silicon, but a more transmittance in visible spectrum. The maximum of diffraction efficiency for PLSM was achieved for the write light intensity 40 μW/cm^2, a resolution on the one half of maximum of diffraction efficiency was 54 mm^{-1}. The optical response of PLSM was observed in the frequency region from 1 Hz to 100 Hz.

INTRODUCTION

Photosensitive layers being used in photoaddressed spatial light modulators must have high sensitivity for the visible region of spectrum and dark resistivity greater than resistivity of a liquid crystal layer, which is usually equal to 10^{10} - 10^{11} Ohm·cm. The attainment of high photosensitivity in amorphous hydrogenated silicon films (α-Si:H) is not of difficulty. However, the typical values of dark resistance for such films are equal to 10^8 - 10^{10} Ohm·cm. The use of a p-i-n diode instead of "intrinsic" layer α-Si:H allows to obtain the greater values of dark resistivity at a reversed bias. It is well-known that the introduction of different dopes such as oxygen, nitrogen, carbon into the film also results in increasing the dark resistivity. For example, doping the α-Si:H film by carbon results in broadening the energy band gap, increasing the transmittance for visible light and shift of the spectral photosensitivity into shorter wavelength region.[1]

Two years ago K. Akiyama et al.[2] have described a spatial light modulator with a hydrogenated amorphous silicon carbide (α-$Si_{1-x}C_x$:H) as a photosensor and a ferroelectric liquid crystal (FLC). The α-$Si_{1-x}C_x$:H films were prepared by rf glow discharge (13.56 MHz) from a gas mixture of SiH_4 and C_2H_4 diluted with helium. We have also developed a photoaddressed spatial light modulator (PSLM) with a thin layer of a α-$Si_{1-x}C_x$:H as the photoreceptor and a nematic liquid crystal (NLC).

OPTICAL PROPERTIES OF α-$Si_{1-x}C_x$:H PHOTORECEPTOR

Layers of α -$Si_{1-x}C_x$:H were prepared by rf-decomposition of gas mixture of silan and methane. The carbon concentration in the films was varied by changing the silan and methane flows. The volume ratio ($k = CH_4/SiH_4$) was changed from 0 to 45 %. To obtain the required properties of the films we studied the influence of the gas mixture composition on the dark resistance, spectral transmittance and photosensitivity of the prepared films. Fig.1 shows a spectral transmittance of the α-Si:H (k = 0) and α-$Si_{1-x}C_x$:H (with k = 30 % and k = 45 %) layers of 1.2 μm thick. The transmittance edge of α-SiC:H is shifted of about 100 nm in a shorter wavelength region as compared to the α-Si:H layer. The α-$Si_{1-x}C_x$:H film has a good absorption for the light wavelength shorter than 500 nm while it shows a high transmittance (T = 55 %) for wavelength (λ = 633 nm). The film α-SiC:H absorbs light with λ = 633 nm and shorter, and is transparent for the wavelength longer than 700 nm. When the part of methane in the working mixture has been increased from 0 to 45 %, the dark resistance of the layers increased from 10^{10} to 10^{14} Ohm·cm. However, in this case the photosensitivity of the device decreases. For example, if the specimens are exposed to white light of 1 mW/cm^2 intensity, the contrast ratio of dark resistance to to white light of 1 mW/cm^2 intensity, the contrast ratio of dark resistance to photoresistance ρ_d/ρ_{ph} changes depending on the quantity of introduced carbon, from 10^4 to 10^2.

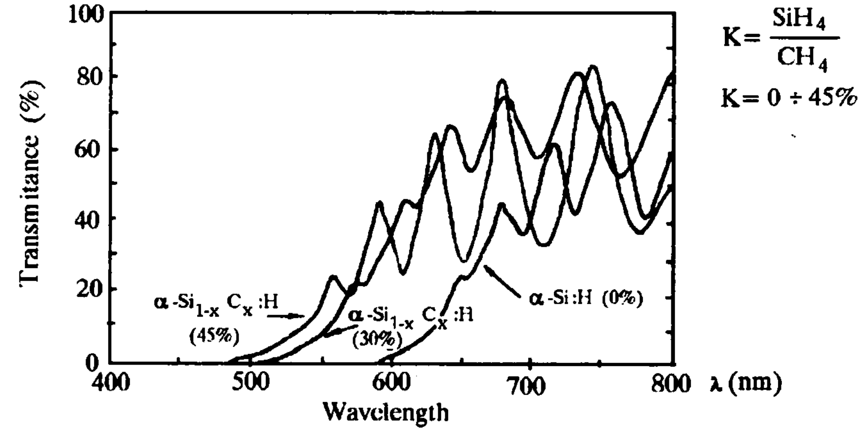

FIGURE 1 Spectral transmittance of the α-Si:H and α-$Si_{1-x}C_x$:H films.

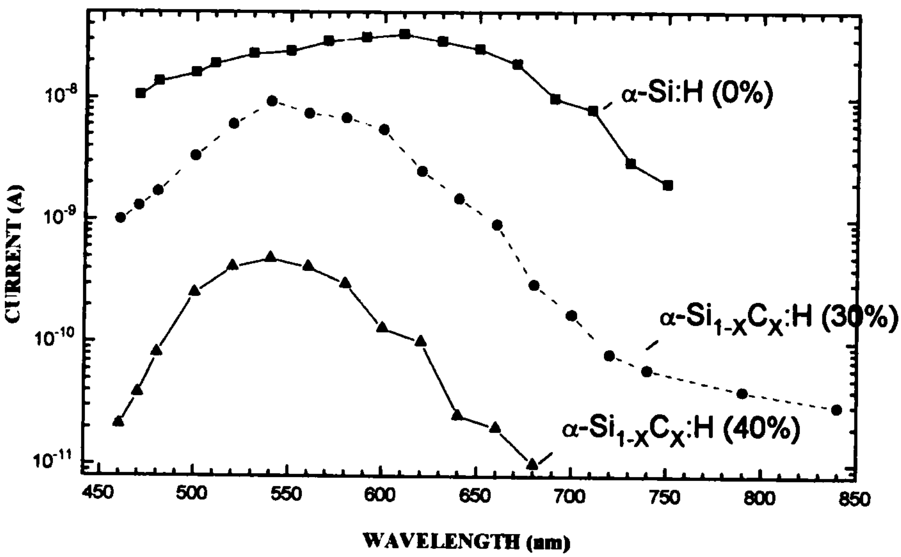

FIGURE 2 Spectral photo currents of α - Si : H and α-$Si_{1-x}C_x$:H films.

spectral sensitivity for an amorphous silicon carbide is shifted to a shorter wavelength region as compared to α-Si:H. This shift increases with an increase of the carbon composition in the film. The decrease of the absolute sensitivity of the $\alpha\text{-}Si_{1-x}C_x\text{:}H$ layers is compensated by a lower value of dark currents, and as a result the relative sensitivity remains sufficiently high.

STRUCTURE OF PSLM

Layers $\alpha\text{-}Si_{1-x}C_x\text{:}H$ obtained for k = 30 % were used for producing PLSM. The thickness of the layers was about 1.2 μm, dark resistance was equal to 10^{13} Ohm·cm and the ratio $\rho_d / \rho_{ph} = 10^3$. The modulator had an usual structure consisting of $\alpha\text{-}Si_{1-x}C_x\text{:}H$ photosensor and layer of a nematic LC of 2 μm thick sandwiched by two glass substrates with transparent electrodes of indium tin oxide. Obliquely evaporated layers of cerium dioxide were used as an alignment layer for a LC. We used nematic crystal with $\Delta\varepsilon = 9.9$ and $\Delta n = 0.164$. The electrooptical twist-effect was used for the modulation of the reading light. For driving the PSLM an unipolar pulse voltage is applied to the electrodes. An amplitude A is equal to 50 V. The frequency varied from 1 to 100 Hz with ratio of pulse width to period of 1:2.

OPTICAL PERFORMANCE

We used a holographic technique for studying the modulator characteristics. The experimental set-up is shown in Fig.3. An interference pattern of two plane wavefronts was formed at the photosensor-LC boundary with a He-Ne-laser light. The intensities of a reference and object beams were equal. The readout was performed by a continuous radiation of a semiconductor laser of a wavelength ($\lambda = 845$ nm) in a transmission mode. The reading light intensity was always 5 mW/cm^2. We studied the behaviour of the diffraction efficiency in the first order of diffraction depending on the write light intensity, driving voltage frequency and the spatial frequency of a holographic grating being formed. The diffraction efficiency was determined as a ratio of the light intensity in the first

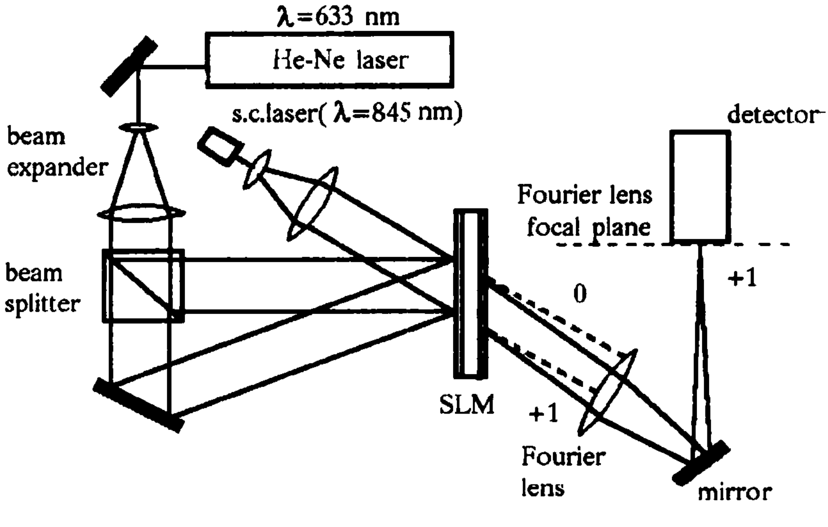

FIGURE 3 Experimental set-up for measuring diffraction efficiency of PSLM.

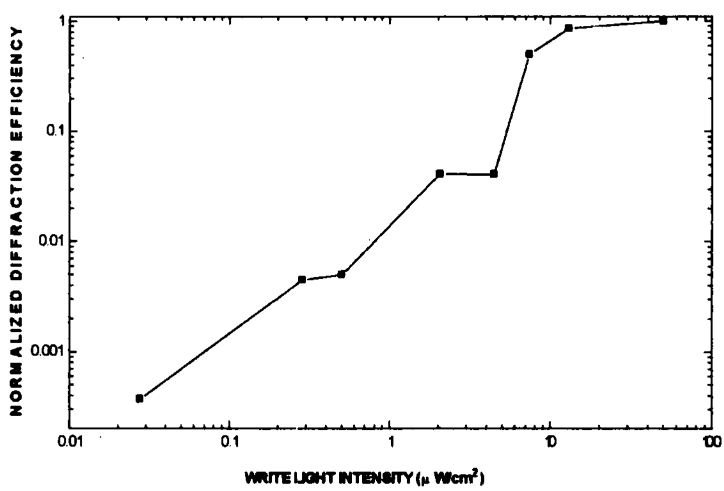

FIGURE 4 Diffraction efficiency dependence on the write light intensity.

diffraction order to the reference beam intensity. The light intensity in the first order was measured by either a photomultiplier or a vidicon, which were placed in the Fourier-lens focal plane. The diffraction efficiency as a function of the writing light intensity is given on Fig.4. From this curve we can estimate the sensitivity of the modulator. The maximum η is achieved for the writing light intensity equal to 40 $\mu W/cm^2$.

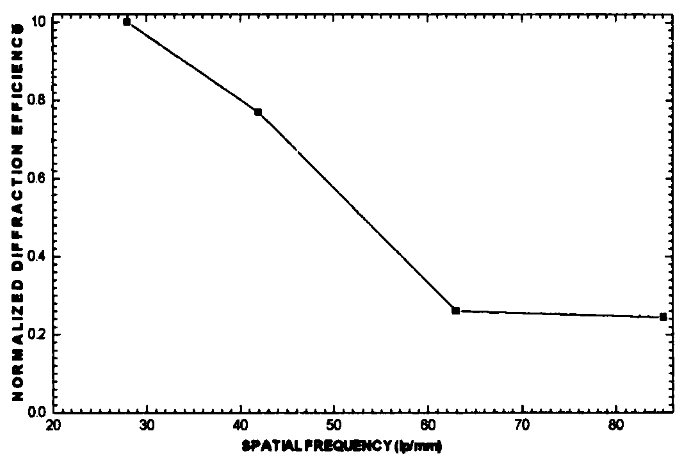

FIGURE 5 Diffraction efficiency dependence on the spatial frequency.

Fig.5 shows the dependence of η on the frequency of the diffraction grating. The spatial frequency was varied by changing the angle of interfering beam's convergence. The value of the resolution at the level equal to one-half of maximum η was equal to 54 mm^{-1}. The resolution limit was not measured because we could form the interference grating with ν_{max} equal to 84 mm^{-1}. Such a high resolution resulted from the high dark resistance of the layer α-$Si_{1-x}C_x$:H and its small thickness.

The dependence of η on the driving voltage frequency is given on Fig.6. From these curves we could estimate the response of the PLSM. At low frequencies the PSLM photoresponse has time for a complete relaxation by the moment of the next driving pulse. At higher frequencies the reversibility of the recording of the holographic grating if achieved by the erasing effect of the next driving pulse. The complete erasure of the previous grating takes place for the frequency region from 1 Hz to 50 Hz. Thus we have the value of the response time which is maximum for the modulators with nematic LC.

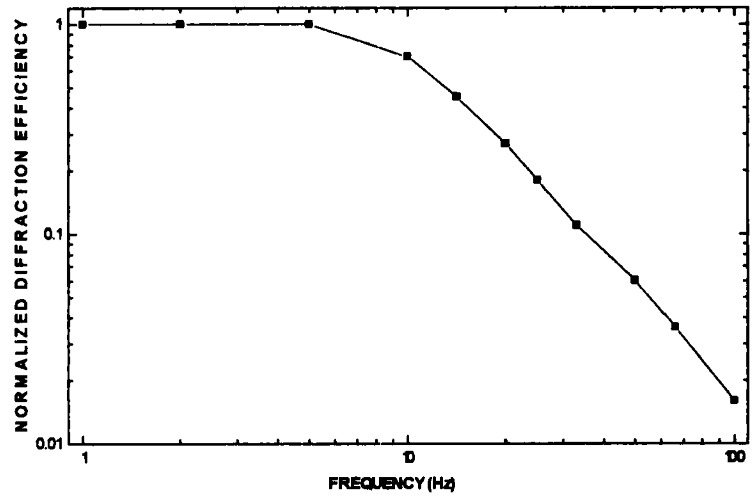

FIGURE 6 Diffraction efficiency dependence on the supply voltage frequency.

We have also produced PLSM of the reflection type with a discrete metal mirror positioned between the photoreceptor and LC. In this case we used a green write light and red reading light.

Layers α-Si_{1-x} C_x:H can be easily doped by introducing phosphine and diboran into the working mixture of silan and methane. In near future we are going to develop the modulators with a p-i-n diode α-Si_{1-x} C_x:H and a smectic LC to receive a faster response.

CONCLUSION

We have described a photoaddressed spatial light modulator with thin film of α-$Si_{1-x}C_x$:H as a photoreceptor and nematic liquid crystal. Such a modulator has the characteristics similar to those of the modulator with amorphous hydrogenated silicon.[3] Transmittance of α-$Si_{1-x}C_x$:H in visible spectrum increases with increases of carbon content x. Consequently the modulators with this photosensor can be used for writing and reading out in visible spectrum in a transmission mode.

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