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Hydrogenated Amorphous Silicon Carbide Photoreceptor for Photoaddressed Spatial Light Modulator

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A highly photoconductive hydrogenated amorphous silicon carbide photoreceptor with a PIN configuration has been prepared by a plasma CVD method using SiH_4 and C_2H_2 heavily diluted with He. Using this photoreceptor, a photoaddressed spatial light modulator (PASLM) which operates in a transmission mode, has been fabricated with a ferroelectric liquid crystal. The PASLM exhibits a response time ~50μs and a contrast ratio of ~30:1 under a write light of 1.5mW/cm^2 intensity, and a resolution of over 180 line pairs /mm.

1. INTRODUCTION

A photoaddressed spatial light modulator (PASLM) with a photoreceptor and a liquid crystal is one of the key components in optical information processing system and displays. Many kinds of PASLMs have been developed. But almost all of them operate in a reflection mode, because the photoreceptor with a low transmission for a visible light has been used, such as CdS[1], GaAs[2], c-Si[3] and thick ($\geq 2\mu$m) a-Si:H[4]. To expand the availability of the PASLMs in an optical information processing and an optical computing, a PASLM operating in a transmission mode has been desired. Hydrogenated amorphous silicon carbide (a-$Si_{1-x}C_x$:H) has been expected as a material to fabricate a thinner and more transmissive photoreceptor because of its high dark-resistivity and wide energy gap. However, the photoconductivity of a-$Si_{1-x}C_x$:H film is much lower than that of a-Si:H, so none of the PASLMs have actively used a-$Si_{1-x}C_x$:H films as a photoreceptor.

Recently, the authors have obtained a highly photoconductive a-$Si_{1-x}C_x$:H film by rf glow discharge of source gases, SiH_4 and C_2H_2, heavily diluted with He[5]. In this work, we have succeeded in depositing a highly photosensitive and transmissive a-$Si_{1-x}C_x$:H photoreceptor using this He dilution method, and we have fabricated a PASLM using this a-$Si_{1-x}C_x$:H photoreceptor.

2. ELECTRICAL PROPERTIES OF A-$Si_{1-x}C_x$:H PHOTORECEPTOR

Figure 1 shows photoconductivity (under AM-1 light of 100mW/cm^2) as a function of optical band gap (E_g^{opt}), determined by using the $h\nu$ vs. $(\alpha h\nu)^{1/2}$ plot, for undoped a-$Si_{1-x}C_x$:H films prepared by the He-dilution and the conventional methods. In both method, the substrate temperature was fixed at 300℃ during the deposition. In the He-dilution method, a SiH_4/C_2H_2/He mixture with 3.5x10^{-3} of a volume ratio ($SiH_4+C_2H_2$)/He was used. The conventional films were prepared with a SiH_4/C_2H_2/He or $SiH_4/C_2H_2/H_2$ mixture and the

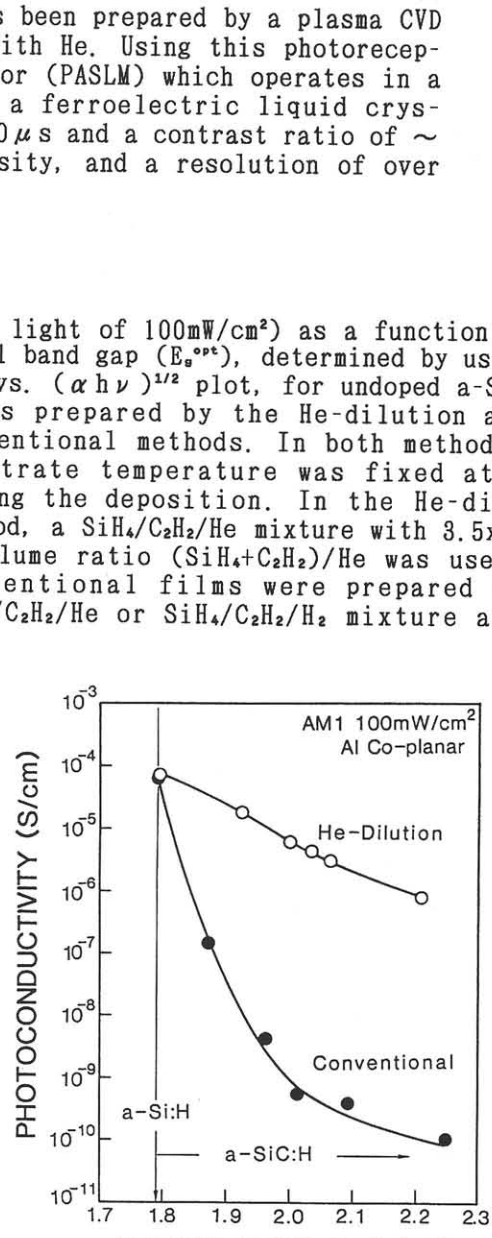

Fig. 1 Photoconductivity as a function of the optical band gap for undoped a-$Si_{1-x}C_x$:H films prepared by the He-dilution and the conventional methods.

volume ratio (SiH_4+C_2H_2)/He (or H_2) was in a range from 0.1 to 0.5. In both methods, the photoconductivity decreases with the increase of E_g^{opt} as well as carbon content (x), but the photoconductivity of the He-dilution a-$Si_{1-x}C_x$:H films is approximately four orders of magnitude higher than that of the conventional films in larger E_g^{opt} than 2eV. The "He-dilution" film of E_g^{opt} =2.0eV, which was corresponding to x=0.2, was used to fabricated a photoreceptor.

The photoreceptor consists of a PIN structure with a total thickness of ~1 μm, realized high transmittance (≧50%) for a light of longer wavelength than 600nm. A boron-doped p layer ~500Å is deposited on an indium tin oxide (ITO) layer as a transparent electrode, followed by an undoped intrinsic layer 8000Å thick and a phosphorus-doped n layer ~1400Å in thickness. Figure 2 shows spectral photo- and dark-currents of the PIN a-$Si_{1-x}C_x$:H and the PIN a-Si:H photoreceptor under applying reverse bias, respectively. For the measurement of the current, samples were prepared by evaporating an aluminum electrode (1000 Å thick; 2.9x2.9 mm in size) on the n layer. The photocurrent measurement was made under the illumination of monochromatic light of 50 μW/cm^2 intensity. The a-$Si_{1-x}C_x$:H photoreceptor showed a maximum of the photocurrent in a range from 400 to 500 nm in wavelength, and the decrease of the photocurrent in longer wavelength than 500nm was caused by decreasing the number of photons absorbed in the photoreceptor. The dark-resistivity of the a-$Si_{1-x}C_x$:H photoreceptor was an order of magnitude higher than that of the a-Si:H photoreceptor.

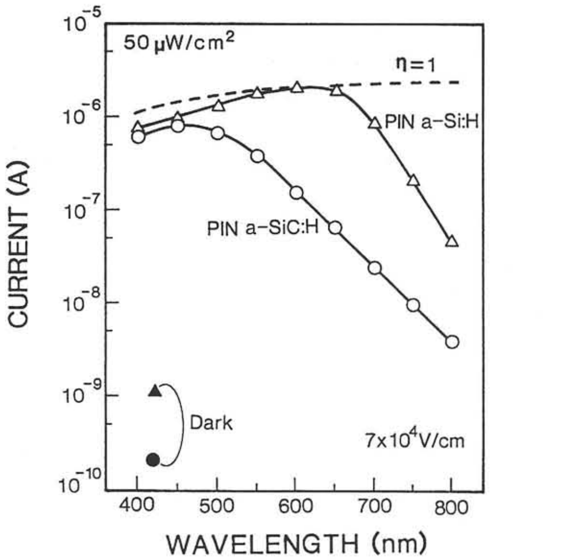

Fig.2 Spectral photo- and dark current of the PIN a-$Si_{1-x}C_x$:H and the PIN a-Si:H photoreceptors. The broken line shows the ideal photocurrent corresponding to the quantum efficiency (η) of 1.

3. DEVICE CHARACTERISTICS

A cross section of the PASLM is illustrated in Fig.3. The PASLM consisted of the a-$Si_{1-x}C_x$:H photoreceptor and a ferroelectric liquid crystal (FLC) layer sandwiched by two glass substrates coated ITO layer. A FLC in a chiral smectic C phase (SmC^*) was sandwiched between the a-$Si_{1-x}C_x$:H photoreceptor and another ITO-coated glass substrate. Using SiO_2 ball spacers, the thickness of the FLC layer was fixed to be ~1 μm. In the PASLM, an optical image was written by a blue or green light and an output was read out by a red light as a transmitted image. A rubbed conductive (10^{10}-10^{11} Ω cm) polyimide film which has been newly developed[6] was used as alignment layers for the FLC as well as the optical neuron device previously reported[7].

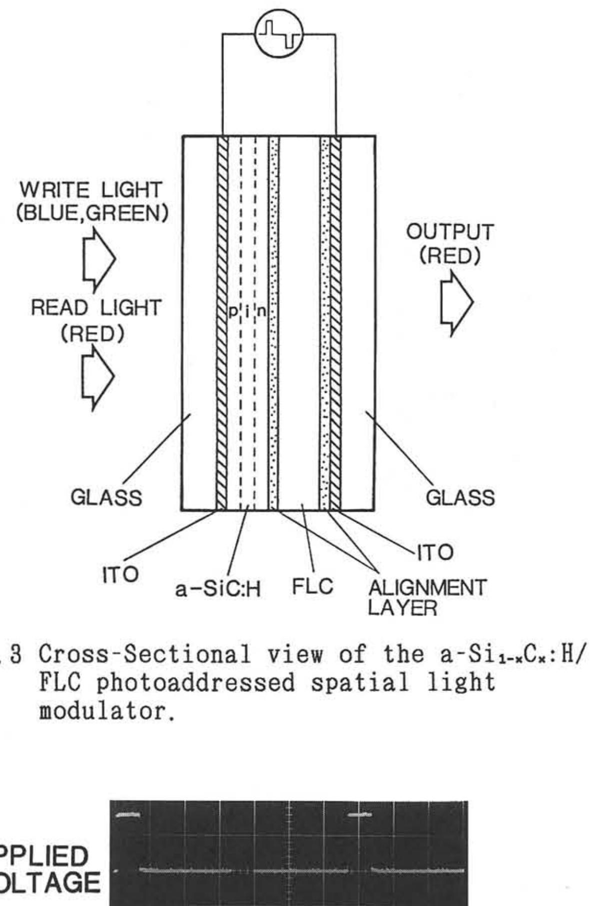

Fig.3 Cross-Sectional view of the a-$Si_{1-x}C_x$:H/FLC photoaddressed spatial light modulator.

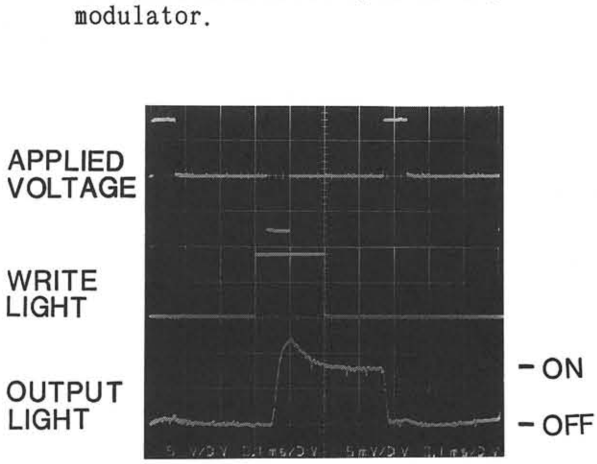

Fig.4 The a-$Si_{1-x}C_x$:H/FLC PASLM responses under 1.5kHz pulsed voltage (V_{p-p}=16V) and modulated write light (1.5mW/cm^2). Horizontal scale : 100 μs/div.

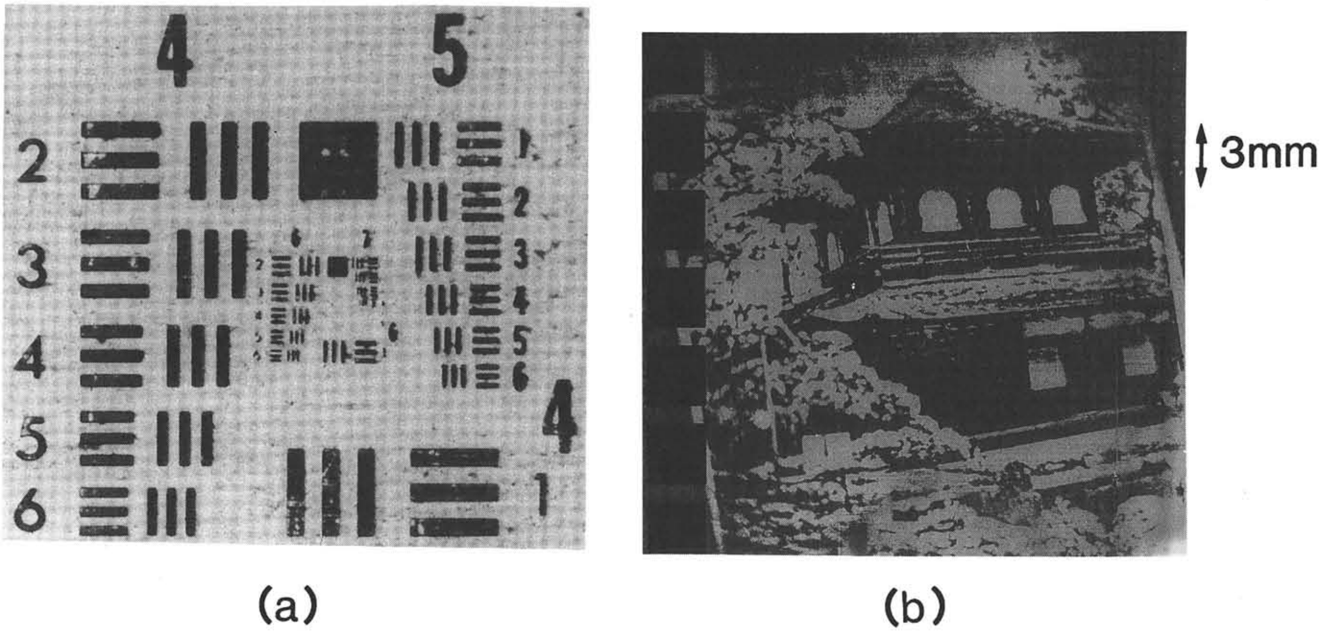

Fig.5 Output images from the a-$Si_{1-x}C_x$:H/FLC PASLM using a green light for writing and a red light for readout (wavelength conversion): (a) binary chart pattern; (b) a photograph printed by the halftone process.

A typical time response of the PASLM to the incident light pulse (λ=563nm) is shown in Fig.4. The upper, the middle and the lower traces show the applied pulsed voltage with amplitude of $16V_{p-p}$ and frequency of 1.5kHz, the write light signal, and the transmitted read light (λ=665nm) response, respectively. The write light with an intensity of 1.5mW/cm^2 was inputted into the PASLM at a reverse-bias pulse. The turn-on response time was ~50μs, this high speed response was caused by the high photosensitivity of the a-$Si_{1-x}C_x$:H photoreceptor.

Two examples of output images of the PASLM are given in Fig.5. The finest pattern shown in Fig.5(a) exhibited a resolution of 160-180 line pairs/mm. The successful output of the halftone image shown in Fig.5(b) was obtained by the high resolution of the PASLM, caused by the high dark-resistivity and the thin thickness of the a-$Si_{1-x}C_x$:H photoreceptor.

The effective area of the PASLM is 35x35 mm, therefore about $4x10^7$ pixel data can be written, stored, read out and erased in parallel in less than 1ms. The PASLM can provide an optical digital computing system with high speed and an optical image processing system with a high resolution.

4. CONCLUSION

We have described a highly photosensitive a-$Si_{1-x}C_x$:H photoreceptor prepared by the He-dilution plasma CVD method and a photoaddressed spatial light modulator using this photoreceptor. This device has operated as a wavelength converter of an optical image from blue or green to red. A high sensitivity, speed and spatial resolution based on high photoconductivity and dark-resistivity of the a-$Si_{1-x}C_x$:H photoreceptor has been shown experimentally in this device. By layering a dielectric mirror on top of the a-$Si_{1-x}C_x$:H photoreceptor, this device can operate in a reflection mode and provide a projection display system with a high resolution.

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