Hologram replication technique in glass plates using corona charging

Daisuke Sakai[a)]
Department of System Engineering, Kitami Institute of Technology, 165 Koen-cho, Kitami, Hokkaido 090-8507, Japan

Kenji Harada and Shun-ichi Kamemaru
Department of Computer Science, Kitami Institute of Technology, 165 Koen-cho, Kitami, Hokkaido 090-8507, Japan

Takashi Fukuda
Photonics Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan

(Received 1 November 2006; accepted 9 January 2007; published online 5 February 2007)

The authors propose a technique of recording in glass plates using corona charging. The recording material used in this study is conventional soda-lime glass. A surface-relief hologram on an azobenzene polymer film coated on a glass plate can be recorded as an electric charge distribution in the glass plate using corona charging. The hologram recorded in the glass plate can be reconstructed as a surface-relief structure on a fresh azobenzene polymer film coated on the glass plate, again using corona charging.
[DOI: 10.1063/1.2459675]

Glass is one of the oldest products in artificial materials. Glass has contributed to the development of humankind; for example, astronomy began from a telescope, and biology began from a microscope. Today, it is almost impossible to avoid the benefits of glass products.

Mechanical grinding, heating drawing, metallic molding, and electron beam machining are application techniques for glass. However, they are mainly surface processes for glass. Although a process that operates inside a glass is required to evolve the functionality of glass further, it has generally been regarded as an impossibility owing to the optical transmission of glass. As a process to solve this issue, irradiation with a focused femtosecond laser is attracting attention. Optical memories using this process that use refractive-index changes or void creation in transparent materials have been reported.[1,2] Additionally, rewritable optical memory has been reported.[3] However, it requires rare-earth ion doping in the glass.

Recently, we have found that a masked pattern can be recorded in glass as an electric charge distribution without shape variation. A surface-relief hologram on an azobenzene polymer film on a glass plate was copied in the glass using a corona charging process without any special treatment of the material.

In this study, a technique of recording in a glass plate using charge distributions is established. Conventional soda-lime glass S-9213 (Matsunami Corp.) was used in this study. A surface-relief grating on an azobenzene polymer film was prepared as mask pattern information. The sidechain polymer polyorange tom-1 was dissolved in cyclohexanone at 10 wt % concentration and then spin coated on a glass plate.[4] The glass transition temperature T_g was 136 °C. The size of the sample was $20 \times 25 \times 1\ \text{mm}^3$. An Ar^+ laser at 514 nm was collimated and exposed to the mirror and to the sample. A grating period of 1 μm and a diffraction efficiency of 2% were obtained. Next, the sample was corona charged. A corona charging technique is often used to align the chromophore orientation to have a second-order nonlinearity. We have already reported an increase in the surface-relief depth on an azobenzene polymer film using corona charging.[5,6] By applying a voltage of 6 kV and heating above T_g for 30 min, the surface-relief depth was increased. A surface-relief grating was observed by atomic force microscopy (AFM), as shown in Fig. 1. Figure 1(a) shows an AFM image before corona charging and Fig. 1(b) shows the image after corona charging. The relief depth was increased from 10 to 400 nm. The first-order diffraction efficiency was increased from 2.1% to 31.0% at a wavelength of 633 nm. The diffraction pattern is shown in Fig. 2(a). After corona charging, the azobenzene polymer film with a surface-relief structure was

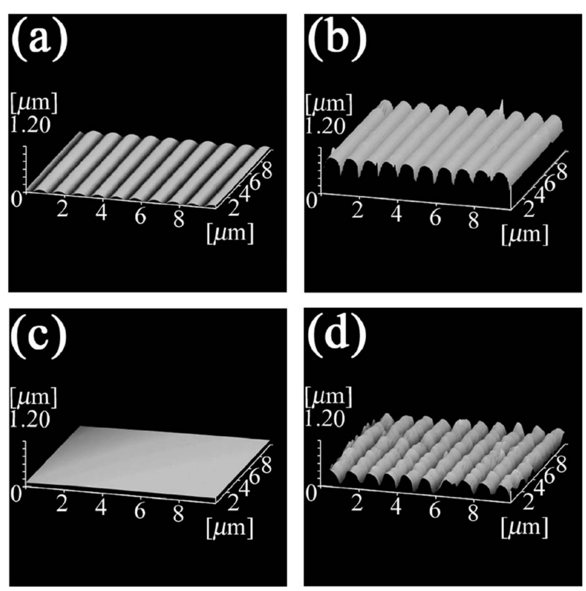

FIG. 1. AFM image of surface profile. (a) After laser irradiation. (b) After first corona charging. (c) After cleaning (only glass). (d) After second corona charging.

a)Author to whom correspondence should be addressed; FAX: +81-157-26-9344; electronic mail: dse06003@std.kitami-it.ac.jp

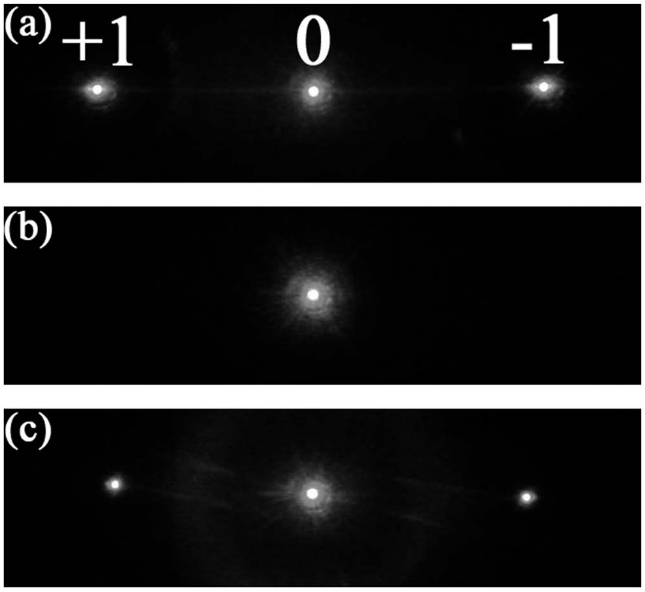

FIG. 2. Diffraction pattern at a wavelength of 633 nm. (a) After first corona charging. (b) After cleaning (only glass). (c) After second corona charging.

removed using acetone in an ultrasonic cleaner. The surface profile observed by AFM is shown in Fig. 1(c). No surface relief is observed on the glass plate. At that time, the first-order diffraction beam was not, of course, obtained from only the glass plate. This is shown in Fig. 2(b). Next, a fresh polymer film was spin coated again on the cleaned glass plate. By using corona charging on the sample again at an applied voltage of 6 kV and heated above T_g for 30 min, the surface-relief grating was reconstructed on the film. The AFM image is shown in Fig. 1(d). Compared with Fig. 1(b), the relief period was unchanged. The diffraction efficiency was determined to be 23.2% at a wavelength of 633 nm, and the diffraction pattern is shown in Fig. 2(c). As a result, the information on the surface-relief grating was recorded in the glass plates using a first corona charging. The surface-relief grating was reconstructed on another film on the same glass plate by a second corona charging. From the resolution of a glass plate measurement, it was found that a grating of 2000 lines/mm can be recorded.

Although the mechanism is not entirely clear at present, we suggest that the mechanism of the recording in a glass plate is as follows. This phenomenon is mainly based on corona charging. Reduction of surface conductivity of poled soda-lime glass was reported by Enami *et al.*[7] They report that surface conductivity of soda-lime glass poled at about 190 °C is 10^{-5} times as high as that of normal soda-lime glass at about 140 °C due to polarization inside the glass. In our procedure, the soda-lime glass plate is covered with an azobenzene polymer film which has a surface-relief structure. A simple hypothesis for the action of the corona-induced electric field is illustrated in Fig. 3. The electrostatic field is produced on the film surface by the first corona charging. The polarization electric fields induced by the electrostatic field exist in the azobenzene polymer film at different strengths at peaks and valleys, respectively. Briefly, the glass plate is more affected by electric fields at valleys than at peaks. Therefore, a surface-relief structure can be copied in the glass plate as an electronic polarization pattern through the process. The surface-relief structure is reconstructed on a fresh azobenzene polymer film by the second corona charging. This is because differing strength of electric field is applied in each part of the fresh film by the polarizations inside the glass plate.

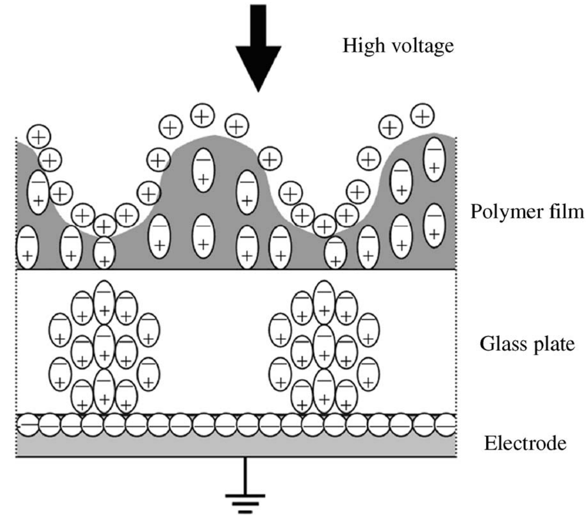

FIG. 3. Illustration of electronic polarization in glass plate.

We also examined a Fourier transform holographic recording in a glass plate using the same technique. The experimental setup for the holographic recording is shown in Fig. 4. A Nd:YVO_4 laser at a wavelength of 532 nm was used as the laser source and irradiated an azobenzene polymer film on a glass plate for 10 min. After recording, a first corona charging was implemented for 30 min. The applied voltage was 6 kV and the temperature was 140 °C. The diffraction efficiency was increased from 0.4% to 2.0% by corona charging. Next, the polymer film was removed using acetone in an ultrasonic cleaner. A fresh azobenzene polymer film was spin coated on the cleaned glass plate. The sample, having no surface relief, was corona charged again at an applied voltage of 6 kV and heated above T_g for 30 min. The Fourier transform hologram was reconstructed on the film using a second corona charging only. Figure 5 shows the reconstructed image at a wavelength of 633 nm. A diffraction efficiency of 0.8% was obtained.

In these experiments, we found that holographic images or characters can be recorded in glass. A charge distribution in the glass plate is stable at room temperature for more than one month and can be erased by immersing the glass in electrolyte solution at room temperature for 2 h or by corona charging the glass plate directly at 140 °C for 30 min.

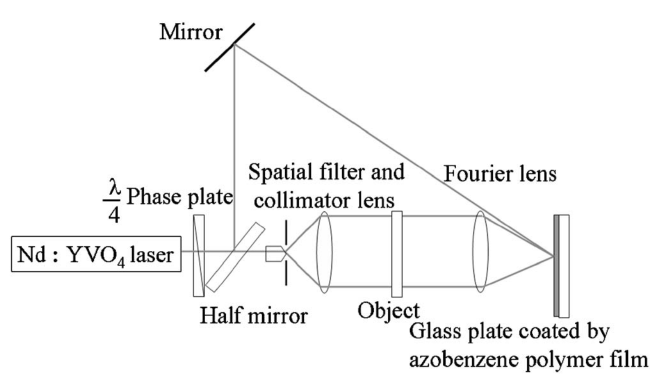

FIG. 4. Experimental setup for Fourier transform holographic recording.

FIG. 5. Reconstructed image at a wavelength of 633 nm.

In conclusion, we have proposed a technique of recording in glass plates that uses corona charging. A surface-relief structure on an azobenzene polymer film can be recorded in glass plates as an electrical charge distribution using a first corona charging, and a resolution of 2000 lines/mm was confirmed. At the same time, there is no shape variation on the glass surface. The relief structure can be reconstructed on another film using a second corona charging. By erasing the accumulated electrical charge, it is possible to rewrite many times. This technique is a promising technique of recording in glass.

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