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Laser Direct Patterning of Organic Dielectric Passivation Layer for Fabricating Amorphous Silicon Thin-Film Transistors

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In this study, a laser direct patterning process application in benzocyclobutene (BCB) organic dielectric passivation-based amorphous silicon (a-Si) thin film transistor (TFT) device fabrication has been carried out using a KrF excimer laser. A BCB organic photoresist material of 2000 nm with a dielectric constant = 2.7 served as the dielectric passivation layer in our device. Compared with conventional processes, laser direct patterning combining BCB organic photoresist dielectric passivation could eliminate at least four process steps. The etching depth of the BCB organic material passivation layer depends on the laser energy density and number of irradiation shots. The hydrogenated a-Si TFT devices are fabricated by replacing the passivation layer and contact hole patterning process. The mobility and threshold voltage reached 0.16 cm^2 V^{-1} s^{-1} and −3.5 V, respectively. For TFT device performance, laser direct patterning technology is a potential method of replacing photolithography technology in the application of BCB organic dielectric passivation-based TFT manufacture. © 2011 The Japan Society of Applied Physics

1. Introduction

Amorphous silicon thin-film transistors (a-Si TFTs) have been widely used in active-matrix liquid crystal displays (AMLCDs). Among the several available a-Si TFT architectures, the back-channel-etch (BCE)-type structure with an indium tin oxide (ITO) pixel electrode on top of the passivation layer is recognized as the most competitive one, in which silicon nitride (SiN_x) is used as the conventional passivation material. The patterning of SiN_x thin films is generally carried out by photolithographic etching in acidic solutions or by plasma dry etching.[1,2] However, simplified processes and more cost-effective technologies have been sought to reduce costs. Laser direct patterning technology and organic passivation layering have become candidates for replacing the photolithographic etching process and the conventional passivation layer.[3–5]

Recently, organic materials deposited on glass by spin-coating or slit-coating have been developed as passivation layers on TFTs by photolithographic and development methods.[6–10] Laser photoablation is an efficient and versatile etching process in which particular regions in a passivation layer can be removed selectively by high-energy UV laser radiation in a one-step patterning process. Thus, it requires no photoresist development, etching, or other process steps before or after the exposure. Other than the material we mentioned above, many researchers have been investigating the feasibility of a laser etching process for metals, oxides, and polymer materials.[11–14] In general, the energy of a laser beam is absorbed at a small depth or small volume and an ablation process takes place through rapid fragmentation.[15] Consequently, no thermal damage or side effect is observed in the neighborhood of the irradiation region or substrate.

In this work, we develop a stable and uniform laser photoablation process for the patterning of a benzocyclobutene (BCB) organic passivation layer. The purpose of the experiment is to investigate the direct patterning of benzocyclobutene (BCB) organic photoresist thin films on a metal/glass substrate (Asahi Glass AN-100) by a laser. The electrical characteristics of a BCB-passivated a-Si TFT device with laser photoablation were also studied.

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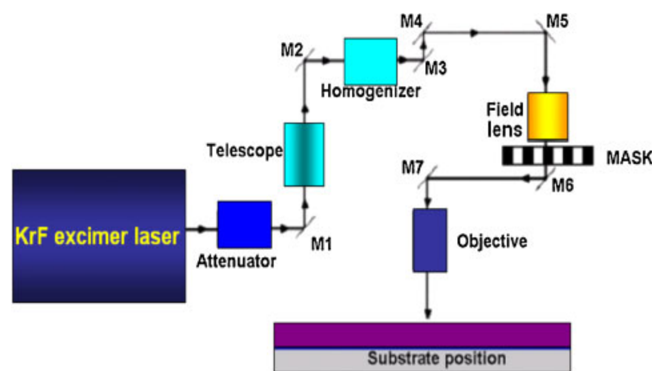

Fig. 1. (Color online) Experimental setup for the laser photoablation of BCB organic thin films.

2. Experimental Procedure

2.1 Laser ablation process

In general, the passivation layer patterning in TFT liquid crystal display (LCD) fabrication is performed by a photolithography process, in which at least five steps are required: photoresist (PR) coating, UV exposure, developing, etching, and PR stripping. Therefore, the process is a high-cost method for the mass production of large panels. In this study, laser photoablation was applied to organic photoresist passivation layer patterning in which only one step is needed.

The experimental procedures of the laser photoablation process are described here. The metal MoW layer (200 nm) and BCB organic (2000 nm) thin films were deposited sequentially on a glass substrate by sputtering and spin coating. The samples were exposed to a KrF excimer laser (Lambda Physik) for which the duration time, wavelength, and repetition rate were 20 ns, 248 nm, and 20 Hz, respectively. Parameters for the laser processing included laser energy density and number of laser irradiation shots. The number of shots increased from 2 to 75, and the energy density varied from 200 to 500 mJ/cm^2. The experimental setup for the laser photoablation is shown in Fig. 1. After the laser processing, the morphology of a sample was observed via scanning electron microscopy (SEM; Hitachi S4700) and

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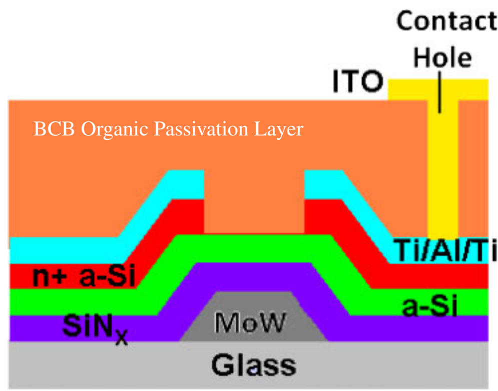

Fig. 2. (Color online) Architecture of a bottom-gate top-contact (BGTC) TFT device.

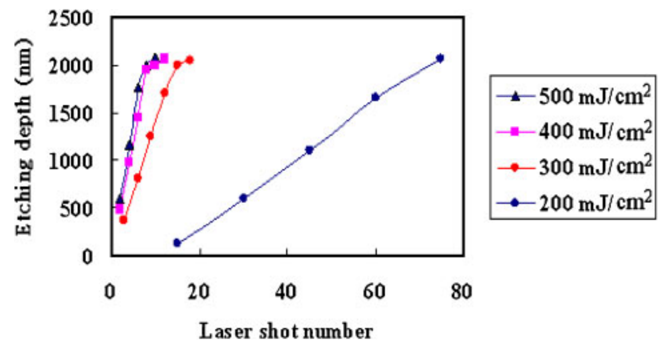

Fig. 3. (Color online) Ablation depth of a contact hole in a BCB organic thin film as a function of laser energy density.

alpha-stepper (α-stepper, KLA core FP-20). The average BCB organic thin film thickness was 2000 nm.

2.2 TFT device fabrication process

The fabrication of inverted-staggered BCE a-Si TFTs with a photoresist organic passivation layer patterned by laser photoablation was carried out in this investigation: The photoresist organic thin film was used as the passivation layer of the a-Si TFT sample, as shown in Fig. 2.

Figure 2 shows the architecture of a bottom-gate top-contact (BGTC) TFT device with $W/L = 80/8$. Metal 1 is made of 1000 Å MoW deposited by sputtering and a trilayer consisting of 500 Å n^+ a-Si/2000 Å a-Si/3000 Å SiN_x deposited by plasma-enhanced chemical vapor deposition (PECVD). 500 Å Ti/1000 Å Al/500 Å Ti serves as metal 2 and the a 7000 Å photoresist as the passivation layer is deposited by spin coating at a higher spin speed than we mentioned previously. The patterning process from metal 1 (MoW) to metal 2 (Ti/Al/Ti) is conventional photolithography, and the contact hole is fabricated by a laser photoablation method. The electrical characteristics are measured with a Keithley 4200 semiconductor parameter analyzer.

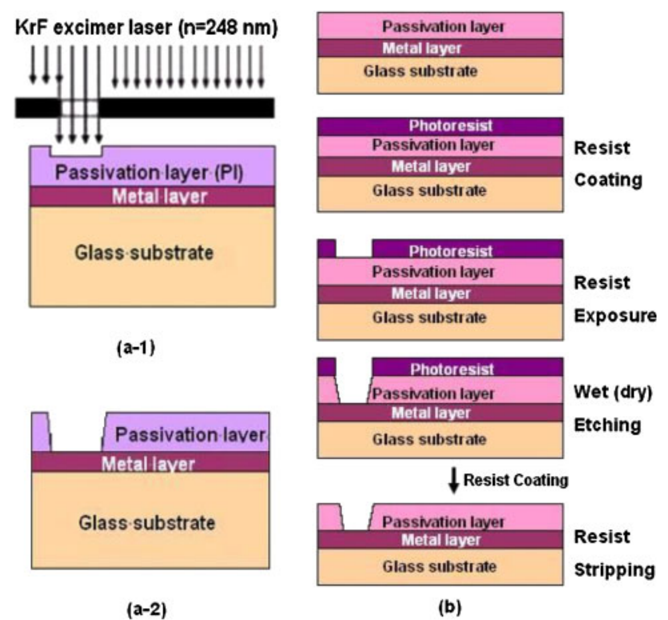

Fig. 4. (Color online) Passivation layer patterning by (a) laser direct patterning and (b) conventional photolithography.

3. Results and Discussion

From Alpha-Stepper (α-stepper) measurements, the laser photoablation etching depths of the BCB organic thin films are shown in Fig. 3. The figure shows the relationship between etching depth and laser photoablation energy density with different laser irradiation shot numbers. The laser energy density varies from 200 to 500 mJ/cm^2, and the BCB organic thin film ablation etching depth increases with laser energy density and irradiation shot number increasing. The ablation rate (etching rate) is almost linearly proportional to the laser energy density and irradiation shot number. With the laser energy density equal to 200 mJ/cm^2 and a shot number of 75, 2000 nm, the BCB organic thin film was completely removed by laser photoablation. Thus, the irradiation conditions of a laser energy density of 200 mJ/cm^2 and 75 shots were determined. This experimental laser photoablation system with the above process conditions produced debris-free patterns of contact holes in BCB organic thin films.

Figure 4 illustrates the concept of this process for patterning BCB organic thin films. For the initial structure, a 2000 nm BCB organic layer was deposited on a MoW/glass substrate by spin coating. The concept of this process for patterning BCB organic thin films is shown in Fig. 4(a-1). A KrF excimer laser with a wavelength of 248 nm was used in a projection imaging configuration in the BCB organic thin-film photoablation process. The beam from the laser was expanded and shaped to fit the mask pattern that was being transferred to the substrate. For the purpose of uniformity, the Gaussian distributed beam will be homogenized to a flab trapezium-like distribution. This pattern is subsequently projected onto the BCB organic thin film. The mask is of the standard chrome-on-quartz type widely used in the semiconductor industry. Such a mask can endure direct irradiation from a KrF 248 nm excimer laser with an energy density as high as 1500 mJ/cm^2. The chrome (Cr)-coated side was replaced to face the BCB organic thin films to avoid damage from direct laser irradiation. As illustrated in Fig. 4(a-2), after the laser process, selective etching with a certain pattern could be obtained.

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Table I. Process step comparison between conventional photolithography and laser direct patterning approach.

Conventional	Laser direct writing
SiN_x deposition	Organic passivation coating
PR coating	
Exposure	Laser patterning
Development	
Etching	
PR stripping	

The main objective of the photoablation process is to remove the patterned BCB organic thin film completely, and to keep the good properties of the nonablated BCB organic thin film after the photoablation process. Owing to the short pulse duration time and the high absorption coefficient of BCB to UV-wavelength light, utilizing a KrF excimer laser is an appropriate method of attaining these objectives. Figure 4(b) exhibits the conventional lithographic technique for the passivation layer. The minimum number of process steps required to pattern the passivation layer by photolithography is 5.

Compared with the conventional process, the laser photoablation process can lead to cost savings in display fabrication, which is mentioned below. In the conventional TFT LCD mass production process, SiN_x is used as the passivation layer material, which is usually deposited using a vacuum deposition system. SiN_x patterning requires five photolithography processes including photoresist coating, exposure, development, etching, and PR stripping. By substituting a SiN_x passivation layer for the BCB organic material, at least four steps, namely photoresist coating, exposure, development and stripping, can be eliminated, as shown in Table I. The reduction in the number of process steps in the display fabrication cycle results in substantial cost savings in high-volume production. Additional benefits come from a reduction in the amount of chemicals used and the associated chemical waste management, which otherwise raises production cost and increases environmental pollution. This process is therefore highly attractive for implementation in TFT LCD fabrication. However, when instrument cost and throughput issues are considered, the increase in excimer laser system equipment cost has to be taken into account. The final benefits of cost reduction for TFT LCDs will depend on production yield and its volume. We will continue to investigate this issue in the future.

Figure 5 shows SEM images of a cross-sectional view of a 2000-nm-deep contact hole pattern in the BCB organic thin films on a MoW/glass substrate to which 15 shots of a laser energy density of 400 mJ/cm^2 are applied. This result indicates that this process can produce contact-hole patterns as precisely as a conventional photolithography process.

A hydrogenated a-Si TFT device fabricated with a BCB organic passivation layer shows good transfer characteristics (drain current–gate voltage: I_d–V_g). The electrical characteristics of a-Si TFTs were measured by a semiconductor parameter analyzer. The BCB organic passivation layer was patterned using a KrF laser with an energy density of 400 mJ/cm^2 and 15 shots.

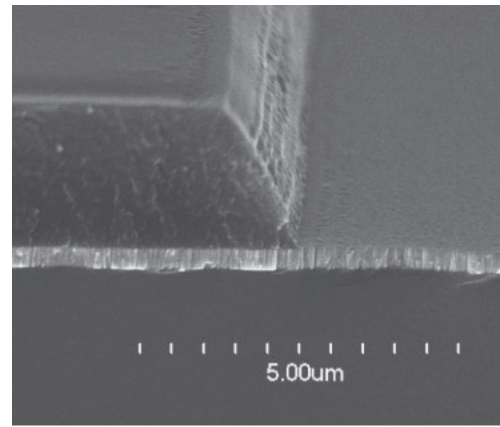
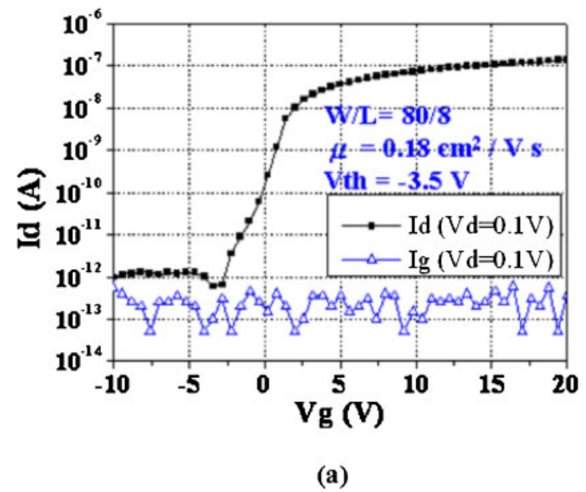


Fig. 5. SEM images of 2000-nm-thick BCB organic thin-film ablation at a laser energy density of 400 mJ/cm^2 with 15 shots.



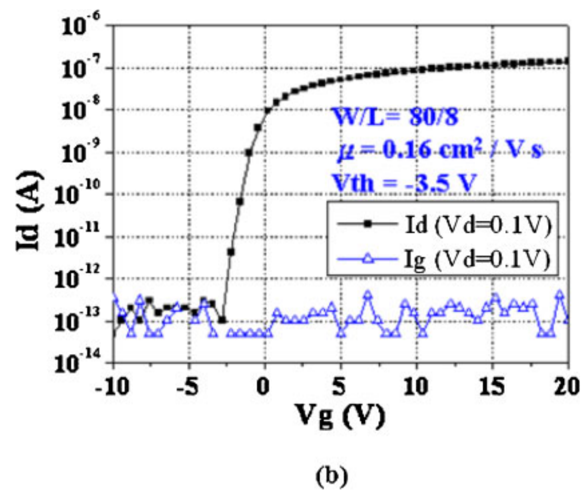


Fig. 6. (Color online) Transfer characteristics of a a-Si TFT with a BCB organic passivation layer. I_d–V_g curves of TFT device with a contact hole fabricated by (a) photolithography and (b) laser direct patterning.

Figure 6(b) shows the transfer curves (I_d–V_g) of BCB organic passivated a-Si TFTs. The device in this investigation had a channel length of $L = 8\,\mu$m and a channel width of $W = 80\,\mu$m. The field-effect mobility (μ_{FE}) and subthreshold swing (SS) were extracted from the I_d–V_g curve

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with a constant drain voltage of $V_d = 0.1$ V. The field-effect mobility (μ_{FE}) was as high as $0.16\,cm^2\,V^{-1}\,s^{-1}$, and the average threshold voltage (V_{th}) was −3.5 V. The off-current was as low as 10^{-12} A, and the on/off current ratio is 10^6 for $V_d = 0.1$ and 10 V. The device characteristics are generally good enough to satisfy LCD application requirements.

In Figs. 6(a) and 6(b), the patterning method was applied and the curve of (b) is better than that of (a). The deterioration of device performance in (a) results from chemical damage during the patterning process, e.g., developer and stripper. No such chemical effect is found in the laser patterning process.

4. Conclusions

We developed a nonlithographic patterning method using laser projection photoablation, which is attractive for the fabrication of TFT LCDs. A KrF 248 nm laser projection ablation technique has been developed for the direct patterning of BCB organic thin films on glass substrates. The new process provides an alternative method of replacing conventional lithographic patterning, and is capable of reducing the number of process steps and production costs. A 2000 nm BCB organic passivation layer was deposited on a MoW/glass substrate by spin coating. The etching rate of the BCB organic passivation layer by laser photoablation depends on the laser energy density and irradiation shot number. From the relationship between the etching depth and the laser energy density, the laser photoablation threshold energy density was found to be $200\,mJ/cm^2$. A KrF excimer laser can effectively ablate 2000-nm-deep patterns in a BCB organic passivation layer with a laser energy density of $200\,mJ/cm^2$ with 75 shots.

The a-Si TFT device fabricated with a BCB organic layer reveals good I_d–V_g transfer characteristics, in which the field-effect mobility (μ_{FE}) and subthreshold swing (SS) were extracted from the I_d–V_g curve with a constant drain voltage of $V_d = 0.1$ V. The mobility and threshold voltage reached $0.16\,cm^2\,V^{-1}\,s^{-1}$ and −3.5 V, respectively. Laser direct patterning technology with a BCB organic passivation layer has the potential to replace photolithography technology in TFT manufacture.

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