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# Patterning of indium tin oxide by projection photoablation and lift-off process for fabrication of flat-panel displays

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Indium tin oxide (ITO), an important material used as a transparent conductive oxide in thin-film transistor liquid-crystal display fabrication, was patterned by a nonlithographic process. First, a $Si_3N_4$ substrate coated with photoresist was patterned by a projection photoablation process using 248 nm wavelength KrF excimer laser radiation. ITO was then deposited by sputtering and patterned by lift-off. The resulting ITO pattern was clean even though it was patterned without the conventional steps of photoresist development and ITO etching. This process technology provides a faster and more economical patterning capability compared to conventional photolithography and etch processes used in the display industry. © *2007 American Institute of Physics*.

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In the fabrication of flat-panel displays and microelectronic devices, a number of complex process steps are required, of which patterning technology is the most important segment because it constitutes the most expensive process in such fabrication. Therefore, innovations in patterning technology, especially for materials such as indium tin oxide (ITO), which is widely used as a transparent conductive oxide in the display industry, will have a significant impact in the production costs of such devices. In this letter, we describe a nonlithographic laser photoablation process for high-quality patterning of ITO films that promises important benefits over current fabrication methods.

Laser photoablation is an efficient and versatile etching process by which selected regions in a polymer layer can be removed by high-energy UV laser radiation in a one-step patterning process, thus requiring no photoresist development, etching, or other process steps before or after the exposure.[1–6] In addition to a wide variety of polymeric materials, in recent years photoablation has also been investigated for laser etching of some metals, oxides, and other inorganic materials.[2,7] One of the reported applications of laser direct ablation is the direct patterning of ITO for device fabrication.[8–10] In these experiments, Nd:YLF and Ti:sapphire lasers with exposure fluences of $10-25\ \mathrm{J/cm^2}$ were used to ablate the ITO (Refs. 8 and 10) and fabrication of an organic light emitting device panel using such processes has been shown.[10] Although the device and panel so fabricated operated well, there were some drawbacks in the results. The ablation of ITO produces stain in the laser illuminated area of the substrate due to the ITO residue and high-energy damage. Besides such stain, even more important problems prevent the process of direct laser ablation of ITO from being used in high-volume production. The pattern linearity after laser ablation of ITO was poor because ITO had physically peeled off during high-energy illumination. With poor pattern linearity, the remaining residue or debris may cause an electrical short between adjacent ITO electrodes. Another important problem is the high laser fluence requirement for direct ablation of ITO. In such a process, the high-energy laser radiation will also illuminate the amorphous silicon (*a*-Si) area in the thin-film transistor (TFT) structure and may remove the ITO above the TFT. The *a*-Si layer may peel off from the substrate because the *a*-Si will decompose into Si and $H_2$ gas.[11] Due to the above major problems in key processes, it is extremely difficult to use direct photoablation of ITO in thin-film transistor liquid-crystal display (TFT-LCD) fabrication.

In this letter, we describe a patterning method that can be used in the TFT-LCD fabrication process to pattern the ITO, and also other layers and structures, without the problems mentioned above. The method consists of two well-known microelectronic processes: UV laser photoablation of a polymer and wet or dry lift-off. Figure 1 illustrates the concept of this process for patterning the thin films of ITO. For the initial structure, a 300 nm thick layer of silicon nitride ($Si_3N_4$) was deposited on a Corning 1737 glass substrate by plasma-enhanced chemical vapor deposition. A conventional photoresist, MicroChem S1818, was then coated and baked on the substrate as the polymer layer. A deep ultraviolet radiation from a KrF excimer laser at 248 nm wavelength was used in a projection imaging configuration for the polymer photoablation process in our experiments, as illustrated in Fig. 1(a). The laser had a pulse repetition frequency of 5 Hz, and provided an incident energy fluence of $50\ \mathrm{mJ/cm^2}$ at the substrate. After the desired pattern was created in the polymer by photoablation, as shown in Fig. 1(b), a 60 nm thick layer of ITO was deposited on the polymer by sputtering [Fig. 1(c)]. For the last step of the process, the photoresist

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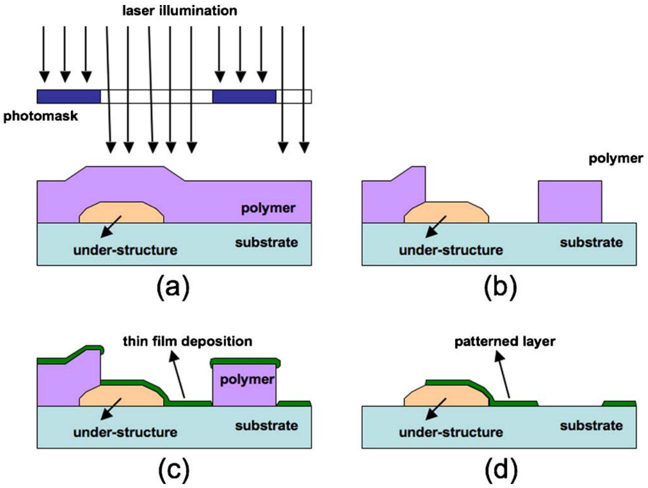

FIG. 1. (Color online) Projection photoablation patterning concept for fabrication of displays and microelectronics: (a) projection imaging of a mask pattern using an UV excimer laser on polymer layer coated on a substrate and an understructure, (b) resulting pattern after the ablation, (c) deposition of the desired thin film (such as ITO), and (d) the final thin-film pattern after lift-off.

was removed in an acetone rinse using lift-off to obtain the final ITO pattern, as illustrated in Fig. 1(d).

This experimental laser ablation system with the above process conditions produced clean patterns of photoresist, as the micrograph in Fig. 2 demonstrates. Although the photoresist was ablated cleanly, some debris was noticed on top of the resist in the unablated areas. However, this did not cause any problems in the final ITO pattern because the remaining photoresist and the debris were removed simultaneously during the lift-off process. Figure 3 shows the resulting ITO pattern on the silicon nitride substrate. Note the cleanliness of the pattern and the sharp edges of the features. The result shows that this process can produce ITO patterns as precisely as a conventional photolithography process. In addition to the ability of this technique to make patterns, it has several merits in cost reduction of display and microelectronic fabrication compared with conventional lithographic processes, as we elaborate below.

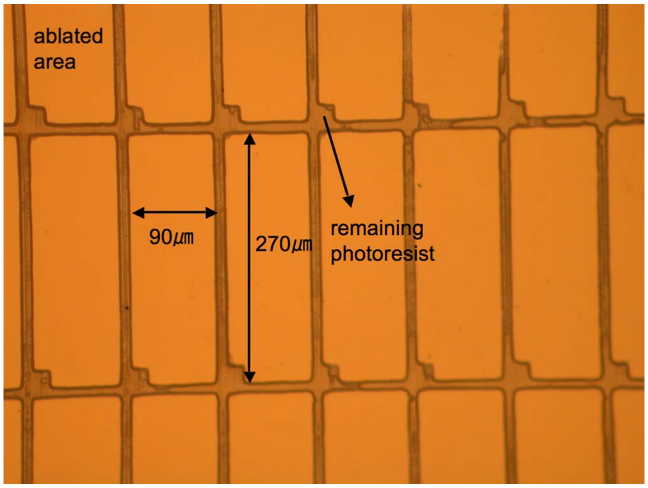

FIG. 2. (Color online) Optical microscope photo of patterns formed in a 2.5 $\mu$m thick photoresist layer on a KrF excimer laser ablation workstation. Using a fluence of 50 $\mathrm{mJ/cm^2}$ at the substrate, the shown patterns were obtained with 30 laser pulses.

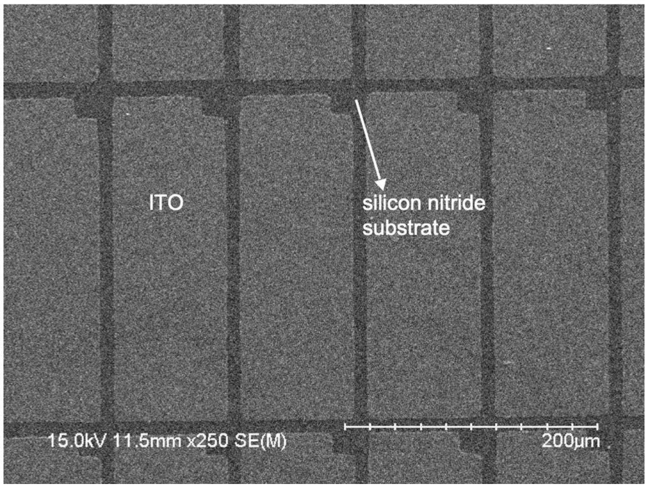

FIG. 3. Scanning electron microscopy photo of a 60 nm thick film of ITO deposited on a $Si_3N_4$ substrate and patterned by the projection photoablation process. Note the clean patterns and their sharp edges.

One of the significant advantages of this process is that it requires fewer process steps than a conventional lithographic patterning sequence. As shown in Fig. 1, the process does not require the developing and the etching steps to create the pattern. A reduction of two process steps in the display fabrication cycle will result in substantial cost savings in high-volume production. Additional savings will also come from the reduced chemical usage and the associated chemical waste management, as the developer and etchant are not needed anymore. The required time for the whole product fabrication process and equipment maintenance will be decreased. For the above reasons, this process is highly attractive for implementation in TFT-LCD fabrication; however, it is also important to address the concern about possible damage to the underlying TFT structure by the excimer laser radiation. Fortunately, the possibility of such laser damage in this process is much lower compared with other photoablation processes for removing ITO. This characteristic comes from two factors of our process. First, the process uses low-

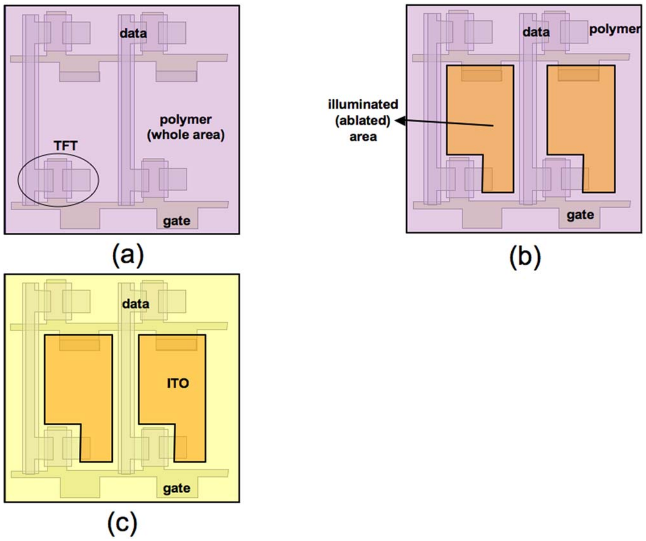

FIG. 4. (Color online) Relationship between the laser illuminated regions, the patterned ITO regions, and the underlying TFT and device regions, illustrating that the laser is never incident on the devices, and therefore this ablation process does not cause any damage.

fluence laser illumination because polymers can be ablated with much lower exposure fluences than ITO. The other factor that minimizes the laser damage comes from the process concept itself, as illustrated in Fig. 4. In the patterning of ITO in TFT-LCD fabrication by this process, the polymer will be coated as shown in Fig. 4(a), and the polymer will be ablated by laser illumination. However, as shown in Fig. 4(b), the laser radiation will not be incident on the TFT. Figure 4(c) shows the resulting final TFT pattern, demonstrating that the TFT area is not illuminated during the ITO patterning process, and therefore not susceptible to laser damage.

In conclusion, we have developed a nonlithographic patterning method using projection photoablation that is attractive for use in the fabrication of flat-panel displays and microelectronic devices. We demonstrated the feasibility of the application of the process by experimentally illustrating how it can replace the conventional ITO patterning process in TFT-LCD fabrication. The resulting ITO pattern was clean and had sharp pattern features, indicating that this process could be a promising technology for TFT-LCD fabrication, capable of reducing the number of process steps, and decreasing costs. We are currently researching the application of the projection ablation process to other materials and other device structures, which will be reported in the near future.

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