Ultrafast laser patterning of organic / inorganic thin-films for OLED / OPV applications

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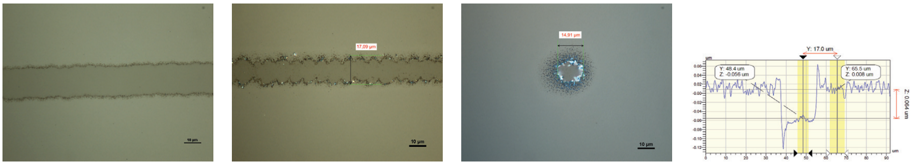
In organic electronics (OLED / OPV) fabrication, thin-film layers consisting of inorganic or inorganic-organic multilayered stack are crucial. Process optimization is challenging as the damage on the barrier layer can lead to the moisture and oxygen penetration into the stack resulting in degradation of the device. Various inorganic and organic thin films on a glass / inorganic-organic barrier substrates are patterned using 355 nm, 532 nm and 1064 nm picosecond laser pulses. The laser pulse interaction with thin films / barrier using static single pulse (determining thresholds) and dynamic patterning, has been optimized in terms of energy, frequency and pulse overlap.

Introduction

Organic electronics is an emerging and rapidly developing technology due to its advantages such as light weight, thinner size and inherent flexibility. In organic electronics devices the major research focus is on the development of Organic Light Emitting Diodes (OLEDs) [1, 2], Organic Photovoltaics (OPVs) [3, 4] and Organic Thin Film Transistors (OTFTs) [5, 6]. These devices are consisting of a layered structure of thin organic and inorganic films. The organic light emitting polymers such as Poly(p-phenylene vinylene) (PPV) and transparent conducting polymers like PEDOT:PSS are commonly in practice [7, 8]. The Poly(3,4-ethylenedioxythiophene): polystyrene sulfonate (PEDOT:PSS) acts as a hole transport layer and sometimes as anode, depending on the application. In case of inorganic materials, the use of Indium Tin Oxide (ITO) has been common as a conducting and transparent anode [9, 10]. Silicon Nitride thin films acts as a barrier, encapsulation layer [11] or passivation layer [12] in organic electronics devices. In order to process thin films, photo-lithographic patterning technologies are used. However, for roll-to-roll production of the organic devices it is advantageous to exploit the potential of selective laser patterning technique [13]. The selective laser patterning of thin polymer films is challenging, especially when it is deposited on a polymeric substrate. Laser selective patterning of thin films on rigid glass substrate has been reported frequently. However, there are only few investigations of thin films patterning on flexible substrates [14, 15, 16]. In selective laser patterning the quality of ablated trenches depends on the wavelength, pulse length, fluence and material absorption characteristics.

In this study, we have investigated an inorganic (Silicon Nitride) and organic (Plexcore) thin film patterning on different substrates for OLED / OPV applications. Silicon Nitride patterning is carried out on ITO substrate with 355 nm / 1064 nm picosceond laser, and Plexcore selective patterning on glass substrate is compared for 355nm / 532 nm / 1064



(a) Patterned track (width = 18 micorns) with 355 nm wavelength (b) Line patterned with 532 nm wavelength (c) Single pulse removal at 1064 nm wavelength (d) Depth profile (depth = 64 nm)

Figure 1: *Selective patterning of Plexcore thin films with 355nm, 532 nm and 1064 nm picosecond pulses.*

nm picosecond laser pulses. Selective ablation of Plexcore thin films on barrier substrate is also summarized briefly. In order to develop processes for selective patterning, the ablation thresholds are determined, and the influence of laser wavelengths on patterning is discussed.

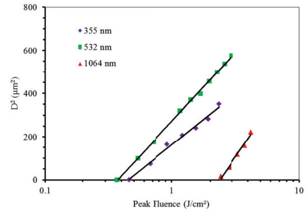
Methodology

Considering the patterning of Plexcore thin films on either glass or barrier substrate, the experiments were conducted using a Time Bandwidth picosecond laser from 3D-Micromac AG, Germany. This set-up can provide three different wavelengths: 355 nm, 532 nm and 1064 nm with different pulse repetition rates. Next, the Silicon Nitride thin films patterning on ITO was carried out at 355 nm and 1064 nm wavelengths using Talisker picosecond laser from Coherent Inc. The analyses of the ablated patterns are performed with optical microscope, depth profiler and scanning electron microscope (SEM).

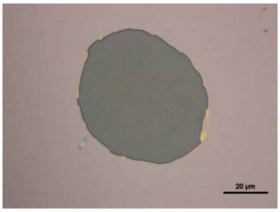
Plexcore patterning

A series of experiments were conducted to study the Plexcore thin film ablation properties using picosecond laser pulses. The patterning with 355 nm wavelength was very successful as shown in Fig.1(a). The ablated line track (width about 18 microns) is clean and no detectable damage on the substrate has been observed in optical microscopic and SEM (not shown here) analysis. The measured depth of the track is approximately 64 nm (Fig.1(d)), which is slightly higher than the actual thickness of Plexcore thin film (60 nm). However, it is difficult to determine the exact depth as the roughness of such plexcore thin film prepared by spin coating also plays an important role.

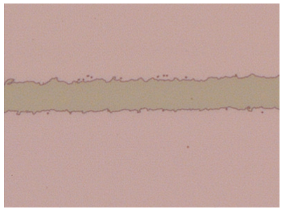
When the experiments were conducted with 532 nm wavelength the selective patterning was successful. The ablated track is clean and debris free as shown in Fig.1(b). The selective ablation in this case is driven by a combination of photochemical and photothermal processes. The line patterning with 1064 nm was difficult, however the single pulse selective ablation was successful (refer Fig.1(c)). The reason for this can be justified as the higher ablation threshold value at 1064 nm wavelength compared to 355 nm / 532 nm wavelengths. The thin film ablation thresholds are determined at different wavelengths with single pulse ablation on a glass substrate and results are plotted in Fig.2(a). These



(a) Ablation thresholds at different wavelengths



(b) Single pulse Silicon Nitride removal



(c) Silicon Nitride patterning on ITO

Figure 2: *Ablation threshold determination for Plexcore thin films; patterning of Silicon Nitride thin films.*

plots clearly indicate the much higher value of ablation threshold for 1064 nm as compared to 355 nm / 532 nm wavelengths.
In a similar fashion, the experiments were conducted for the Plexcore thin film on a flexible barrier foil. At 355 nm wavelength the results show feasibility of patterning on barrier but still under investigation and needs further optimization of the process. However, the higher wavelengths (532 nm / 1064 nm) seems hardly suitable for Plexcore thin film patterning on barrier. It has been observed that on flexible barrier substrate the patterning of thin films is very successful at UV wavelengths [17].

Silicon Nitride Patterning

In the next step, the patterning of inorganic thin films of Silicon Nitrides were tested with 355 nm and 1064 nm wavelengths, picoseocnd pulses. Unlike the organic Plexcore thin films, in this case 1064 nm pulses are able to selectively pattern the Silicon Nitride thin film on ITO substrate. The results are shown in Fig.2(b) (single pulse removal) and Fig.2(c) (line patterning), which indicate that the patterned regions are clean and debris free. The ablation mechanism assumed to be photomechanical in nature. On the other hand, the 355 nm picosecond pulses can not provide the better results in this case. The successful ablation of Silicone Nitride thin film with 1064 nm can be attributed to the substrate influence on patterning [18], as the absorption of ITO plays a crucial role in this case. Hence, this patterning is substrate assisted and it is not always beneficial to have higher absorption of the top layer for selective patterning.

Conclusions

In this work, we have investigated selective patterning of organic and inorganic thin films using different laser wavelengths and picosecond pulses. The selective patterning of organic thin film on glass substrate was very successful, whereas on a flexible barrier the process still needs optimization. In case of inorganic thin film, the patterning was very successful on ITO substrate and the influence of substrate plays an important role on patterning.

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