Strategies for ultrafast laser patterning of multilayer thin film stacks for flexible electronics applications

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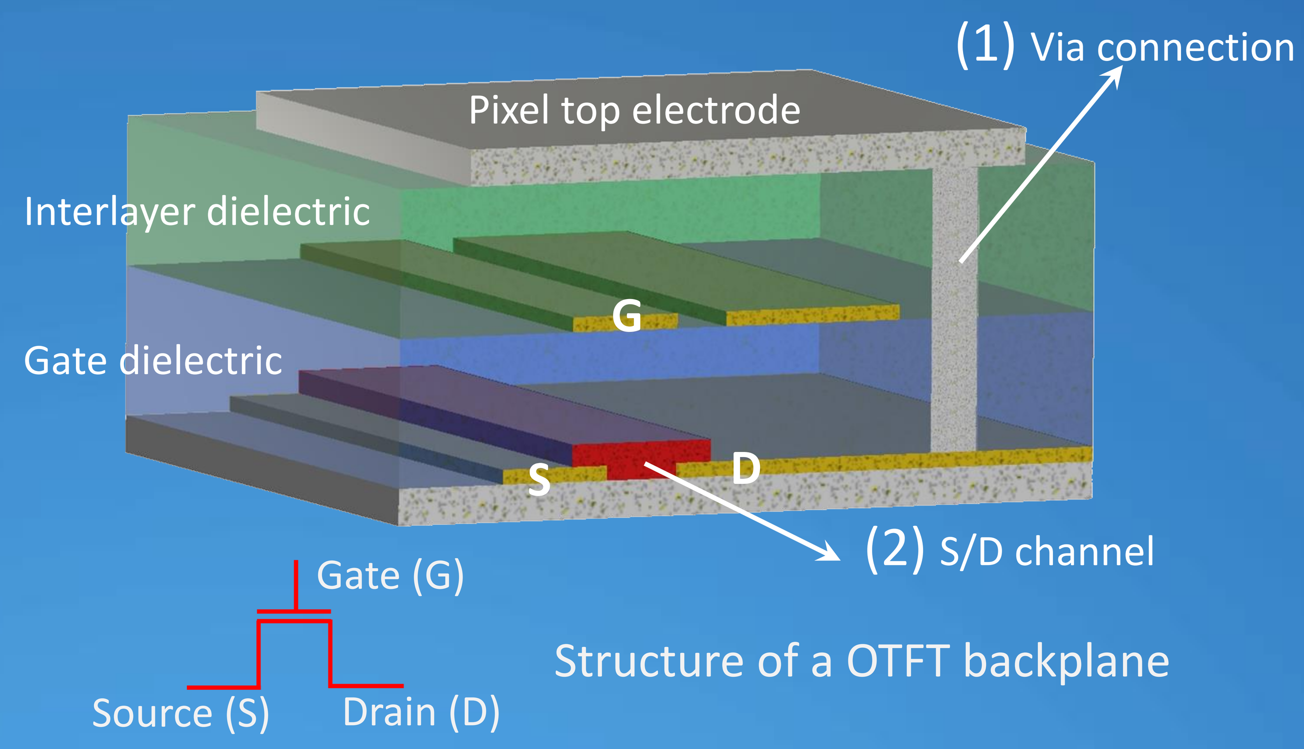
Ultrafast lasers have been extensively employed for sub-µm layer removal in recent years, for the patterning of thin films. Indeed the ultrafast laser is the ideal digital tool for the patterning phases of flexible electronic devices, comprised of thin film stacks of dissimilar materials [1]. However challenges remain to be solved, especially when (i) working close to the ablation threshold of the top layer [2]; (ii) removing a transparent layer from a heat sensitive substrate; or (iii) selectively removing a multilayer feature of non-uniform thickness. This work presents a few strategies to tackle such challenges.

Introduction

The current preferred patterning technique for flexible electronics is photolithography which does not readily allow design modifications. Our aim is to use laser direct writing as a digital and reconfigurable alternative; here it is applied to patterning of OTFT backplanes for manufacturing flexible display and finger print sensors.



Structure of a OTFT backplane

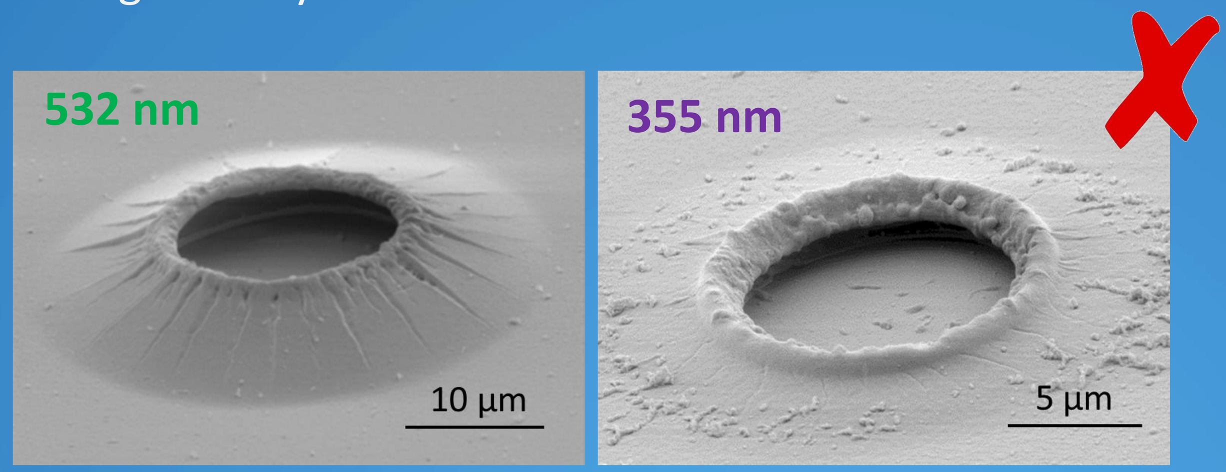
1. **Via interconnection drilling:** Laser percussion drilling of channel linking two conductive layers through one or more transparent dielectric thicknesses
2. **S/D channel patterning:** Separation of transistor source and drain electrodes by laser ablation of a conductive pad over a heat sensitive substrate

Via interconnection drilling

900 nm transparent dielectric over 80 nm gold alloy substrate

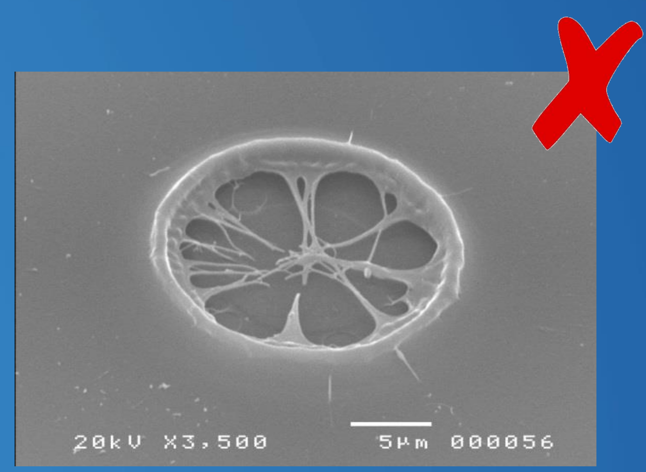
1. Single pulse, 15 ps, 532 and 355 nm

The pulse is absorbed by the metal. Temperature and pressure rises at the metal-dielectric interface lead to a "volcano" shape dielectric delamination. The metal layer is ablated.



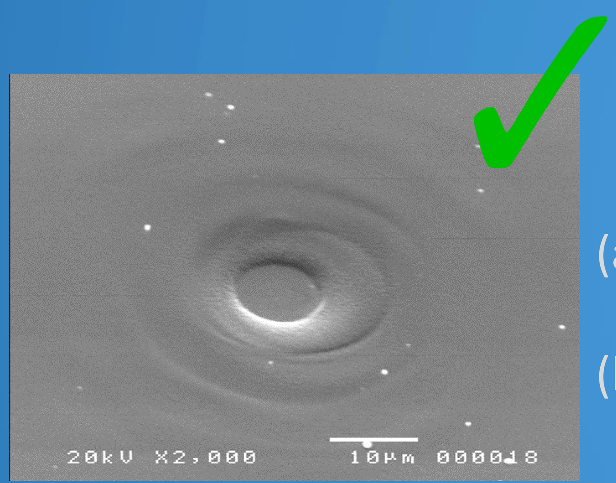
2. Single pulse, 220 fs, 1026 nm

The pulse is absorbed within the dielectric layer. The metal layer is intact but residual dielectric still covers the via



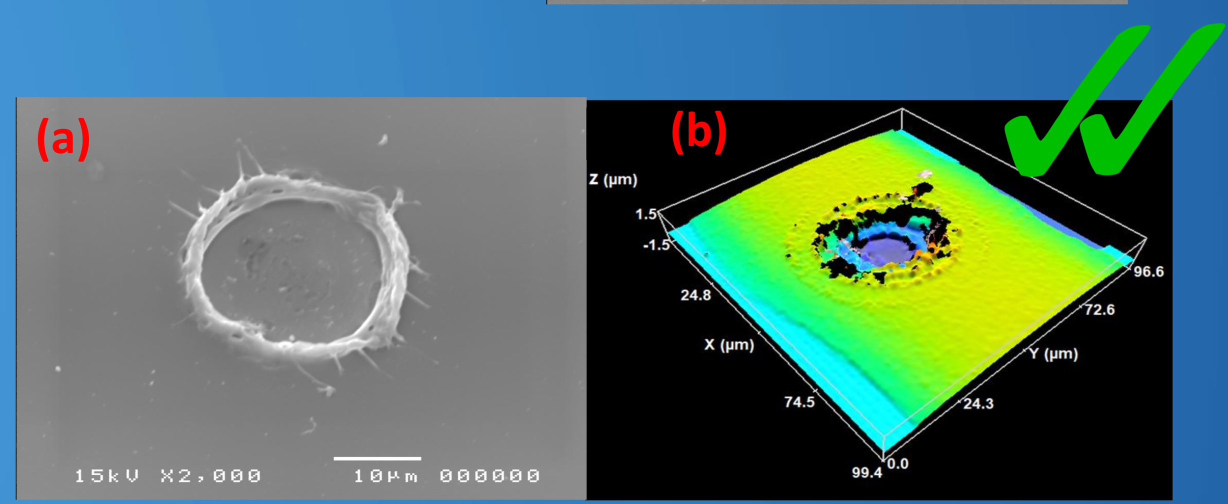
3. 10^8 pulses, 15 ps, 355nm

By continuous exposure to UV radiation the dielectric is removed via photo incubation.



4. Burst of 2 pulses, 220 fs, 1026 nm. 15 ns pulse separation

(a) The burst removes the dielectric without damaging the metal.
(b) Multilayer feature patterning: 700 nm LIFT printed line/ 900 nm dielectric/80 nm metal. Both LIFT line and dielectric are removed without damaging the metal



S/D Channel patterning

80 nm gold alloy layer over flexible polymers

Gaussian spatial intensity profile: Operating not far above the ablation threshold of the top layer avoids damage of the layer immediately below, but degrades edge quality. The process is strongly affected by the number of pulses per area [2]. Channels above were ablated using three times the ablation threshold at (a) 3.8 pulses per area and (b) 8 pulses per area.

Square quasi top-hat spatial intensity profile: Edge quality is better preserved compared to the Gaussian profile case when working just above the ablation threshold of the top layer. A reduced pulse overlap is required to achieve straight edges, hence less power is sent onto the sample. Writing at two times the ablation threshold a single pulse crater (c) and a channel (d) at 1.4 pulses per area

Conclusions

1. **Burst mode improves laser ablation selectivity in ultrafast laser drilling of thick transparent dielectric layer over non transparent thin substrate**
2. **Top hat intensity profile improves channel edges and broadens the working window close to ablation threshold of the top layer**

[1] N. Bellini, R. Geremia, S. Norval, G. Fichet and D. Karnakis, "Laser Thin Film Patterning for Rapid Prototyping and Customised Production of Flexible Electronics Devices", JLMN **11**, 388, (2016).
[2] R. Geremia, D. Karnakis, D. P. Hand "The role of laser pulse overlap in ultrafast thin film structuring application" Appl. Phys. A **124**, 640, (2018).

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