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# Selective laser ablation of transparent flexible bi-layer foils

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**Abstract**

Flexible electronics is an emerging industry, which requires of a further improvement of specific manufacturing technologies to process plastic electronic materials. PET-ITO bi-material foils constitute one of the most common transparent flexible substrates used today in flexible electronics. In this work, we report on the capabilities of a laser ablation process for micromachining and structuring flexible bi-layer PET-ITO substrates. In particular, a femtosecond pulsed laser has been employed in order to engrave microchannels with geometrical features in the range of tens of microns on the PET substrate and to selectively eliminate the ITO coating.

Keywords: Laser ablation; femtosecond; transparent flexible electronics; PET-ITO; micromachining;

## 1. Introduction

Flexible electronics play a key role for the new generation of a wide range of optoelectronic devices, like sensors, microfluidics or displays [Wong and Salleo, 2009; Nathan et al., 2012; Liu et al., 2017]. Their unique properties, such as light weight, conformability or ruggedness have awakened interest from both industry and consumers. However, manufacturing technologies for electronic materials need to be upgraded in order to overcome the future challenges of flexible electronics applications [Jain et al., 2005]. Semicrystalline polyethylene terephthalate (PET) coated with an indium tin oxide (ITO) layer is one of the main transparent flexible substrates used today in optoelectronic applications [Zardetto et al., 2011]. This work reports the capability of a femtosecond pulsed laser at its fundamental wavelength (1030 nm) and its second harmonic (515 nm) for the micromachining and structuring of PET-ITO foils.

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## 2. Experimental procedure

Commercial ITO-coated (50 nm coating thickness) PET films, with a good electrical conductivity and a total thickness of 52 microns were micromachined and structured by a laser ablation process.

An Ytterbium fibre femtosecond laser (Satsuma $HP^2$ from Amplitude Systemes) operating at its fundamental wavelength (1030 nm) and its second harmonic (515 nm) was employed to investigate the capability of the laser ablation process for patterning transparent flexible PET-ITO foils. The repetition rate of the laser system was set to 250 kHz and different pulse energies (from 2 to 40 µJ for the IR wavelength and from 1 to 20 µJ for the VIS wavelength) were used. The femtosecond laser source was combined with a galvanometer scanner and two different f-theta lenses (32 and 163 mm focal length) to scan the focused laser beam on the surface of the PET-ITO substrate, while this remained at rest. Figure 1 shows the schematic diagram of the experimental setup for the laser ablation experiments.

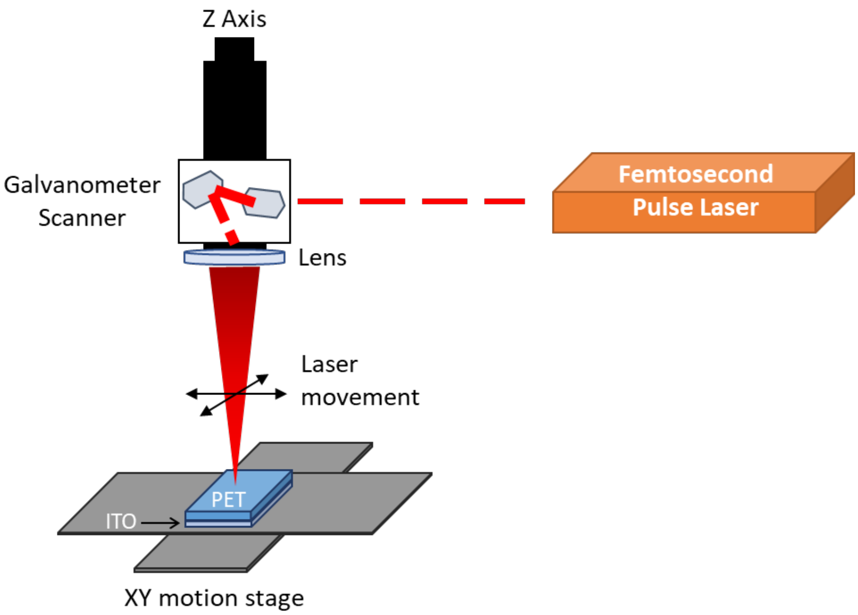


Fig. 1. Schematic diagram of the laser experimental setup

Ablation experiments consisted of engraving microchannels on the PET-ITO foils by a multi-pulse overlapped process, with a laser pulse overlap of 95%. The laser beam was always focused on the PET layer.

Topography and geometrical features of the fabricated microchannels were determined by a Sensofar S-Neox confocal microscope.

## 3. Results and discussion

### *3.1. Visible wavelength experiments*

Both f-theta lenses (32 and 163 mm focal length) were employed for fabricating microchannels with a laser pulse overlap of 95% and pulse energies from 1 to 20 µJ.

Figure 2 collects the results obtained with the visible wavelength and the lens of 32 mm focal length. For this wavelength and this lens, microchannels obtained for medium pulse energies (between 6 and 14 µJ) present the best morphological features, with an aspect ratio close to 1.5 and low roughness. Microchannels fabricated at these energies have a depth between 15 and 24 microns, and a width between 23.5 and 36.5 microns respectively.

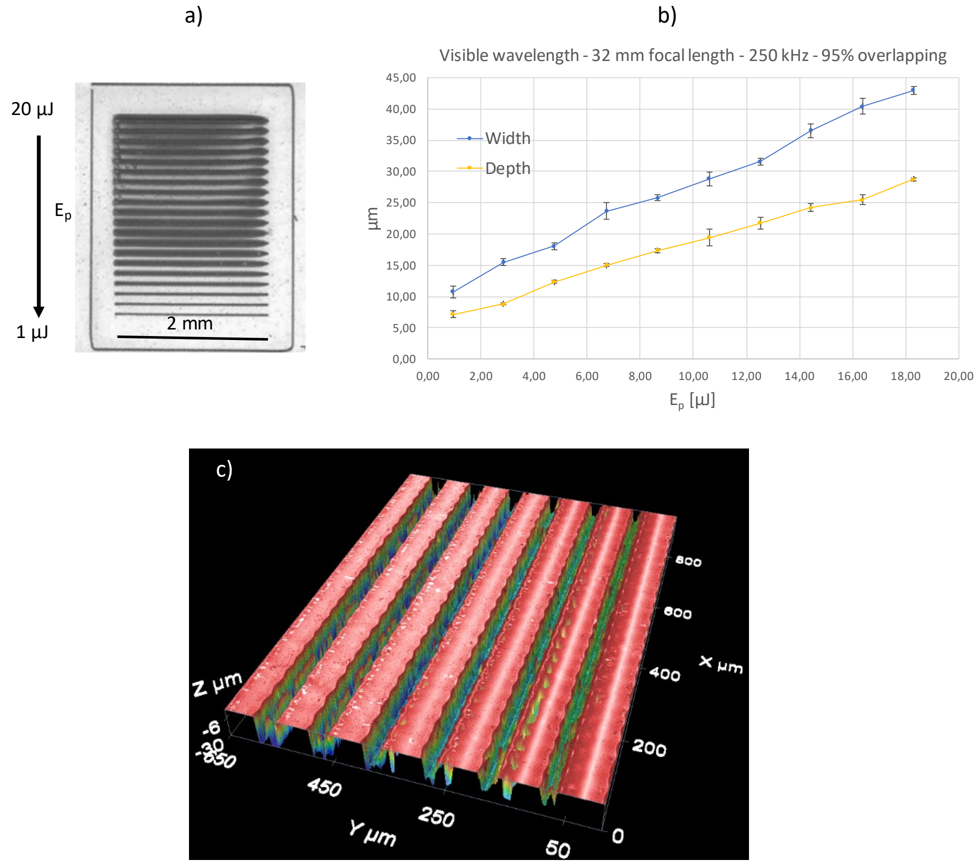


Fig. 2. Microchannels fabricated with the visible wavelength and the lens of 32 mm focal length: (a) optical image and (b) geometrical features (width and depth) of the microchannels obtained from 1 to 20 µJ pulse energy and 250 kHz; (c) 3D confocal image of the microchannels fabricated at medium pulse energies

Next, Figure 3 shows the results obtained with the visible wavelength and the lens of 163 mm focal length. In this case, only the microchannels fabricated with a pulse energy higher than 6 µJ have been engraved on the PET substrate. For pulse energies below this value, the material's ablation threshold (minimal laser energy required to remove material from a substrate) is not reached. Microchannels engraved on the PET substrate present a good morphological quality, with well defined walls and without thermal damage. Their depth goes from 15 to 37 microns and their width goes from 33 to 58 microns; with an aspect ratio close to 2.

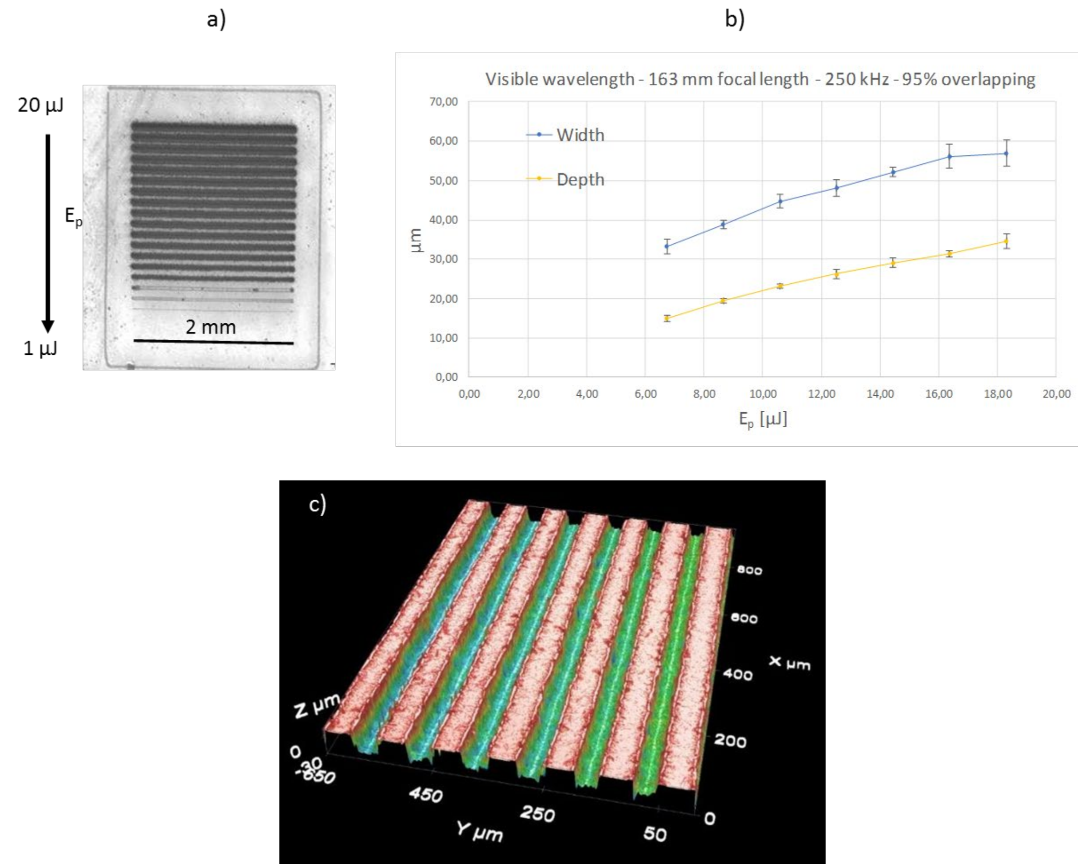


Fig. 3. Microchannels fabricated with the visible wavelength and the lens of 163 mm focal length: (a) optical image and (b) geometrical features (width and depth) of the microchannels obtained from 1 to 20 µJ pulse energy and 250 kHz; (c) 3D confocal image of the microchannels fabricated at medium pulse energies

### *3.2. IR wavelength experiments*

Again, both f-theta lenses (32 and 163 mm focal length) were employed for fabricating microchannels with a laser pulse overlap of 95%, in this case pulse energies went from 2 to 40 µJ.

Results obtained with the lens of 32 mm focal length are presented in Figure 4. Microchannels fabricated with the IR wavelength present a greater thermal effect (as it can be appreciated in the edges of the microchannels shown in Figure 4.c) than those fabricated with the visible one. For this particular case, only microchannels obtained at pulse energies below 10 µJ present a minimal thermal damage and good morphological features, with an aspect ratio close to 1. These microchannels have a depth between 15.5 and 25 microns and a width between 16.5 and 25 microns.

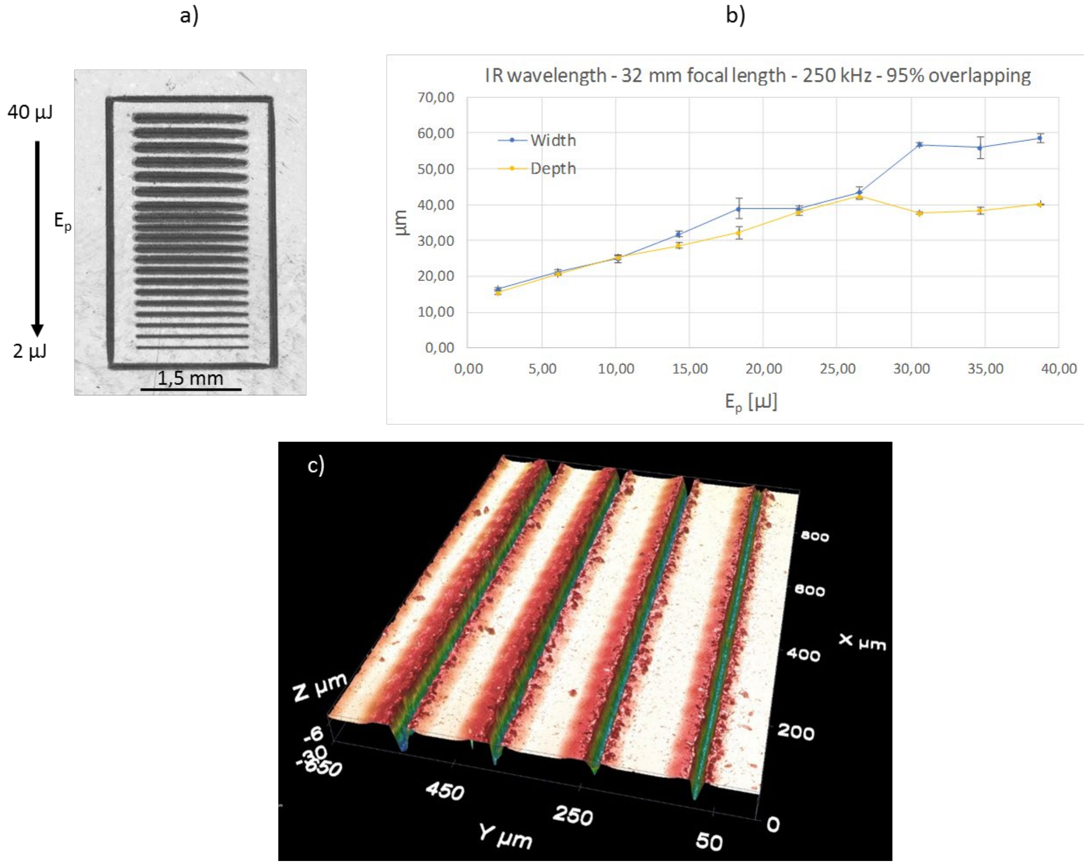


Fig. 4. Microchannels fabricated with the IR wavelength and the lens of 32 mm focal length: (a) optical image and (b) geometrical features (width and depth) of the microchannels obtained from 2 to 40 µJ pulse energy and 250 kHz; (c) 3D confocal image of the microchannels fabricated at medium pulse energies

In the case of using the IR wavelength at 95% pulse overlap, focused with 163 mm focal length lens, results obtained do not enable the proper microstructuring of the PET substrate without damaging the ITO coating. For this reason, experiments at 75% pulse overlap were done. In this case, for low pulse energies the laser beam goes through the PET substrate without causing any damage and is absorbed by the ITO coating, enabling its selective laser ablation (see Figure 5).

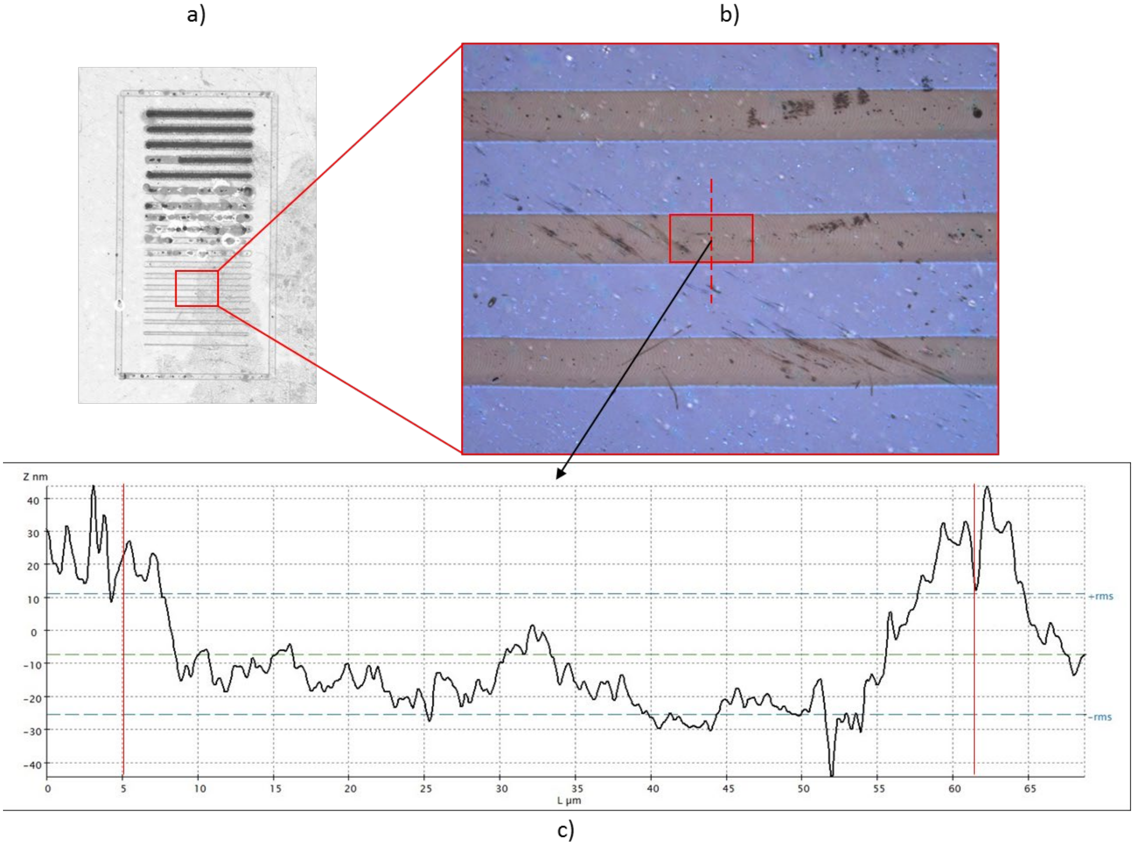


Fig. 5. Selective laser ablation of the ITO layer at 75% overlap: (a) optical image; (b) detail of the microchannels engraved and (c) topographic profile of one of the microchannels, where the elimination of the 50 nm ITO conductive layer is shown.

Figure 5 confirms the clean removal of the ITO layer (grey in figure 5-b) exposing the PET substrate (blue-violet in Figure 5-b) with little to no damage, as revealed by the topographic profile obtained with confocal microscopy, which shows a very flat surface in the laser ablated line, with an overall roughness below 10 nm, and an ablation thickness (in the few tens of nm) which corresponds with the ITO layer thickness. The absence of any remaining of ITO in the ablated track and the clean and well defined limit of the ablation track also verifies the process capability to perform quality and reliable isolation and structuring. Moreover, the experiment confirms a wide process window to produce this selective ITO ablation with minimal to no damage to the substrate, in this case energies from 2 to 16 µJ for a beam spot diameter of 50 µm, and overlaps of 75%.

## 4. Conclusions

The feasibility of using a femtosecond laser at both IR and visible wavelength for the successful micromachining and structuring of transparent flexible PET-ITO foils by a laser ablation process has been demonstrated.

On the one hand, experiments performed with the visible wavelength have allowed for a more precise and efficient micromachining process of the PET substrate. Results obtained with this wavelength show better morphological features and lower thermal damage than those obtained with the IR.

On the other hand, experiments performed with the IR wavelength have promoted the selective ablation of the conductive ITO layer, making possible the generation of electrical circuits in the flexible PET-ITO foils. Further investigations will be done in order to perform a thorough analysis of this particular application of the PET-ITO foils laser processing.

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