Picosecond laser treatment of ITO films on glass

A. J. Clarke, J. Eden, R. J. Farley, A. A. Serkov, H. V. Snelling, C. D. Walton
School of Mathematics and Physical Sciences, Faculty of Science and Engineering, University of Hull, HU6 7RX
J. Lee
Rofin-Sinar UK Ltd, HU13 ODG

Abstract

Laser processing of transparent conductive oxide (TCO) films is a promising research area, mostly due to their applications in computer screens and photovoltaic cells. One can notice, however, that most researchers trying to alter the electric properties of the films (e.g. their conductivity) are employing either UV pulsed lasers [1] or far infrared CW sources [2]. Infrared pulsed lasers of pico- and femtosecond pulse duration ranges are mainly used for laser ablation of the films [3, 4] (apart from some rare exceptions [5]). In this work, we present new results on picosecond laser irradiation of spin-coated ITO films on glass. The effects of laser irradiation on surface morphology, as well as the crystalline structure of the film are investigated. It is shown that laser treatment leads to a substantial decrease in the film sheet resistance whilst retaining its transparency in the visible range. Obtained results present picosecond laser irradiation as a viable alternative to conventional annealing methods, such as CO_2 laser irradiation or furnace heating.

Experimental setup

Radiation source:
USP-100 (Rofin-Sinar UK Ltd): wavelength of 1030 nm, pulse duration of 1 ps, average power of 100 W, repetition rate up to 10 MHz.

Analysis methods:
Morphology: surface profiler (Bruker DektakXT), optical microscope (Leica DM-LM);
Crystalline structure: XRD diffractometer (PANalytical Empyrean);
Optical properties: optical transmission spectrometer (Thermo Scientific Evolution 220);
Resistivity: four-point probe (Jandel, 1 mm probe distance).

Material properties

Initial ITO samples were spin-coated on glass at Leibniz Institute for New Materials. Typical SEM view of the surface is presented in Fig. 1. Main parameters are given in Table 1.

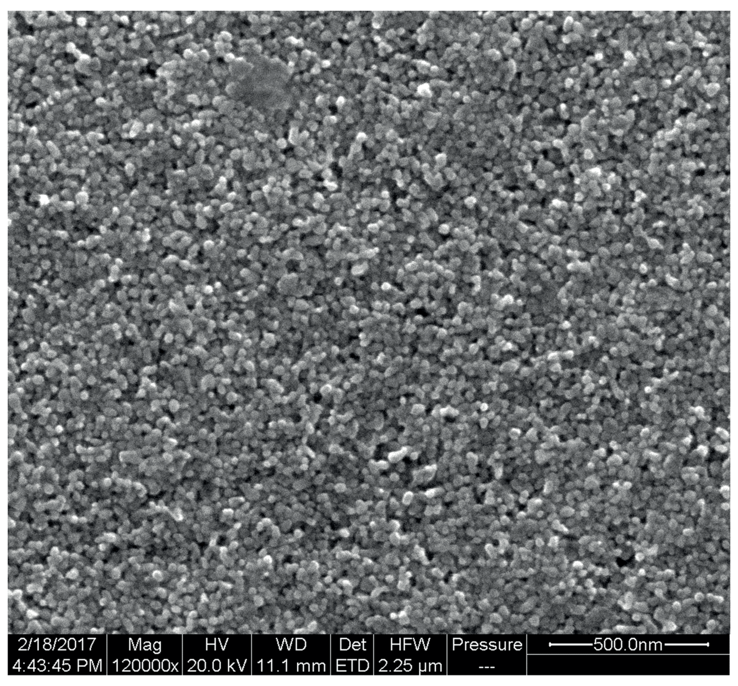

Fig. 1. Typical SEM view of the initial ITO film surface

Substrate	Sheet resistance, kOhm/sq	Thickness, nm	Total transmission, %
Borofloat glass	9.19	505	91.3

Table 1. Main properties of the initial ITO films

Results

The irradiation procedure consisted of two steps: irradiation of the film and irradiated area isolation via laser ablation of the rectangle around it (Fig.2).
In order to investigate the dependence of the ITO film sheet resistance on the laser fluence a series of exposures was carried out (Fig.3). Repetition rate of 5 MHz, scanning speed of 17 mm/s.
The effect of laser irradiation on ITO film thickness was investigated via irradiation of separate lines and measurement of their profiles (Fig.6).

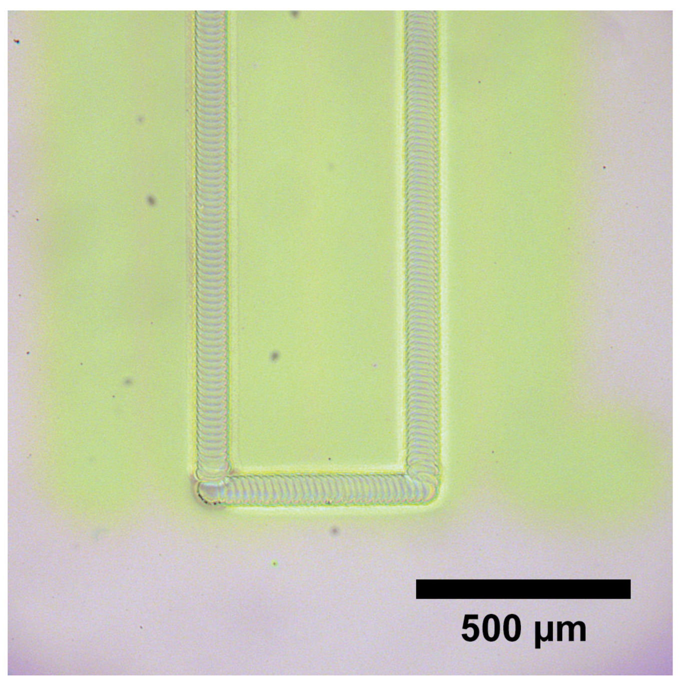

Fig.2. Optical microscope view of a typical irradiated ITO sample

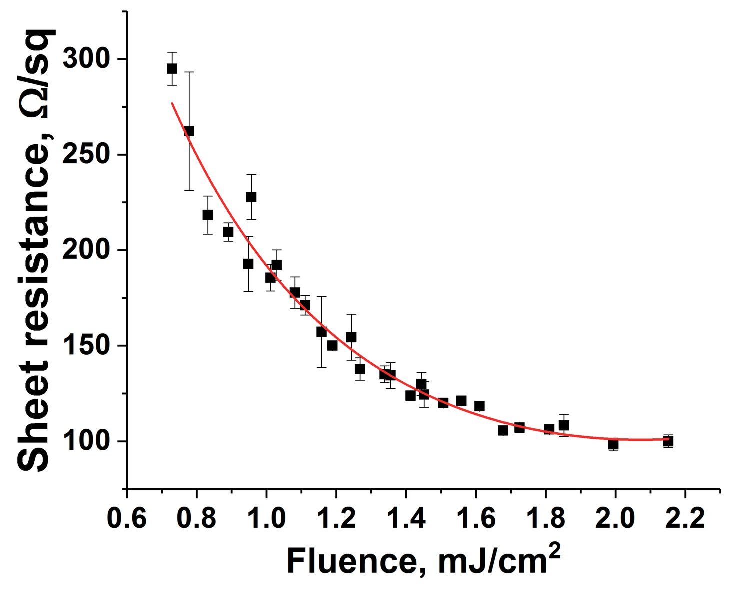

Fig.3. Dependence of the ITO sheet resistance on the laser beam fluence

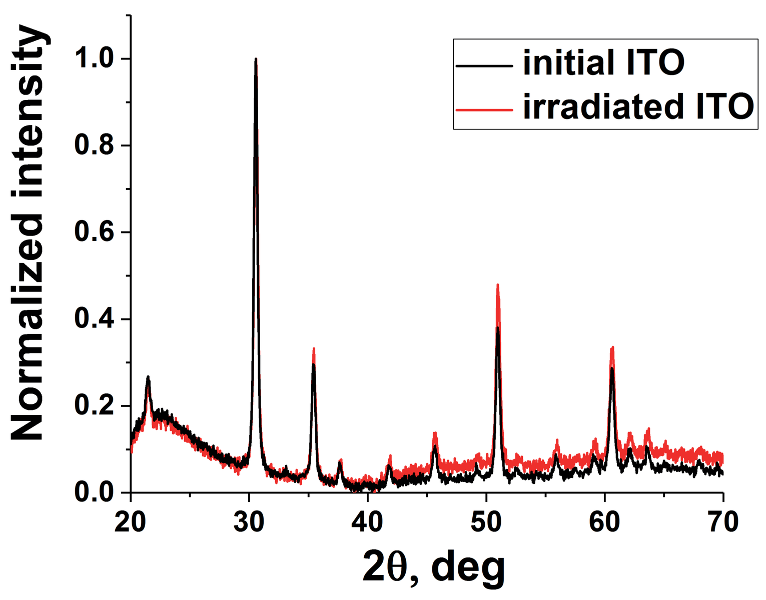

Fig.4. XRD spectra of the ITO films. (fluence of 1.8 mJ/cm²)

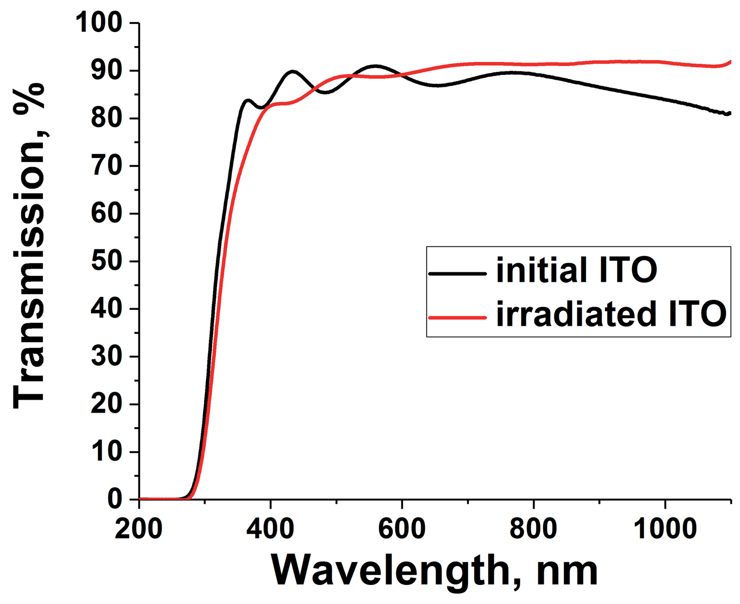

Fig.5. Transmission spectra of the ITO films. (fluence of 1.8 mJ/cm²)

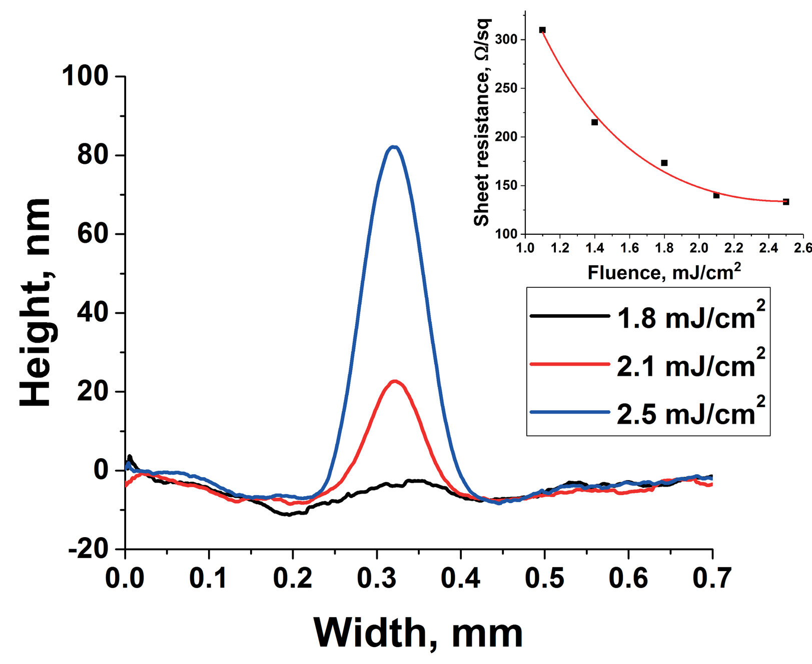

Fig.6. Surface profiles of ITO samples irradiated at different laser fluence values

References

1. G. Legeay, et al., Phys Status Solidi 5.10 (2008): 3248-3254.
2. X. Y. Tao, et al., Appl Phys A 96.3 (2009): 741-749.
3. G. Račiukaitis, et al., Appl Surf Sci 253.15 (2007): 6570-6574.
4. C. McDonnell, et al., Appl Surf Sci 359 (2015): 567-575.
5. M.-H. Chen, et al., ACS Appl Mater Inter 8.38 (2016): 24989-24993.

Conclusions

1. Picosecond laser irradiation results in substantial decrease of the ITO film sheet resistance. The effect is most pronounced at fluences closest to the ablation threshold.
2. Although laser treatment leads to slight changes in film thickness, they do not correlate with the changes in resistivity. The latter most probably are a result of some microscopical phenomenon (such as oxygen vacancy formation) which requires futher investigation.

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