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3D laser structuring of thick composite cathodes to improve solid-state battery performance

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Abstract

3D electrode structuring is of growing interest in the battery field. In recent years, different strategies for such structuring have been addressed and, among them, USP laser technology has emerged as a very attractive approach. Anodes and cathodes have been laser structured, and 3D structures have been found to favor ionic transport in the faradaic electrodes of batteries, thus improving the performance of these energy storage devices. However, the reported works correspond mainly to lithium-ion batteries with liquid electrolyte, while the application of this technology in solid-state batteries has not been explored yet. In the present work, femtosecond laser structuring of solid-state battery cathodes is addressed for the first time. A methodical study of laser process parameters is performed. SEM and optical profilometry are used to analyze the profiles of the generated structures, while XRD analysis is used to evaluate the chemical changes produced in the material by laser processing.

Keywords: Solid-state cells; thick composite cathode; femtosecond laser; 3D structuring.

1. Introduction

High energy density is a crucial issue in the development of high-performance batteries and the use of thick cathodes is an attractive strategy to meet this requirement at relatively low cost. However, they induce limitations to Li ion transport and increase cell electronic resistance, both of which have a negative impact

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on the charging rate of batteries. In order to reduce these adverse effects, several authors have proposed electrode structuring for the current generation Li-ion cells. Different structuring techniques have been presented and laser processes are also emerging (Dunlap et al, 2022, Park et al., 2022, Smyrek et al., 2019). Here we address the 3D structuring of thick composite electrodes for next-generation solid-state cells using femtosecond laser technology.

2. Experimental

In this work, 90 um-thick composite cathodes with $LiFePO_4$ (LFP) as electroactive material have been used. The experimental setup for laser processing is shown in figure 1. A Satsuma HP laser from Amplitude has been used as the femtosecond laser source. A series of optical elements allows the power, size and polarization of the laser beam to be managed. A scanning head consisting of two galvanometric mirrors combined with an F-theta lens controls the scanning strategy.

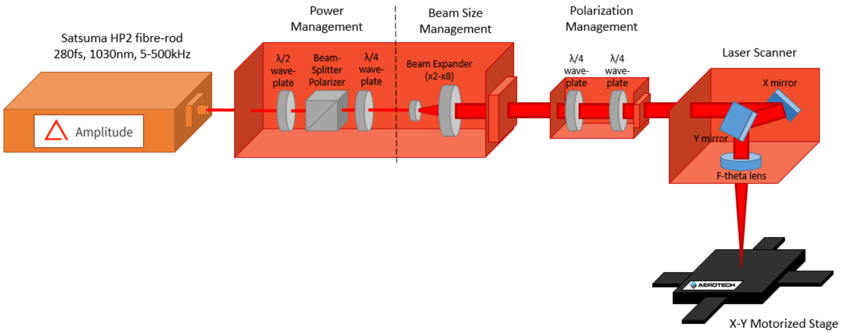

Fig. 1. Laser experimental set-up

The effect of the size and power of the laser beam, as well as the laser scanning speed, on the 3D structures obtained has been systematically studied. Three experimental matrices have been fabricated for 144 different processing conditions. Laser wavelength, pulse duration, pulse repetition rate and beam polarization have been kept fixed in all the laser processes. The laser processing parameters used are listed in table 1.

Table 1. Laser processing parameters

Laser parameter	Value
Wavelength	1030 nm
Pulse duration	280 fs
Pulse repetition rate	50 kHz
Polarization	0º
Beam size (diameter)	10, 20 and 30 um
Beam average power	100 ÷600 mW
Scanning speed	10 ÷ 80 mm/s

3. Results and discussion

Scanning electron microscopy (SEM), X ray diffractometry (XRD) and optical profilometry have been used to characterize the samples. Figure 2 shows SEM images of some of the structures obtained. In particular, trenches with depths of 40, 60 and 80 um processed with three different beam sizes are shown. Figure 3 shows the XRD analysis for pristine and irradiated electrodes. Figure 4 shows the trench depths versus irradiation dose for the three beam sizes considered. The data have been obtained from images captured by the optical profiler.

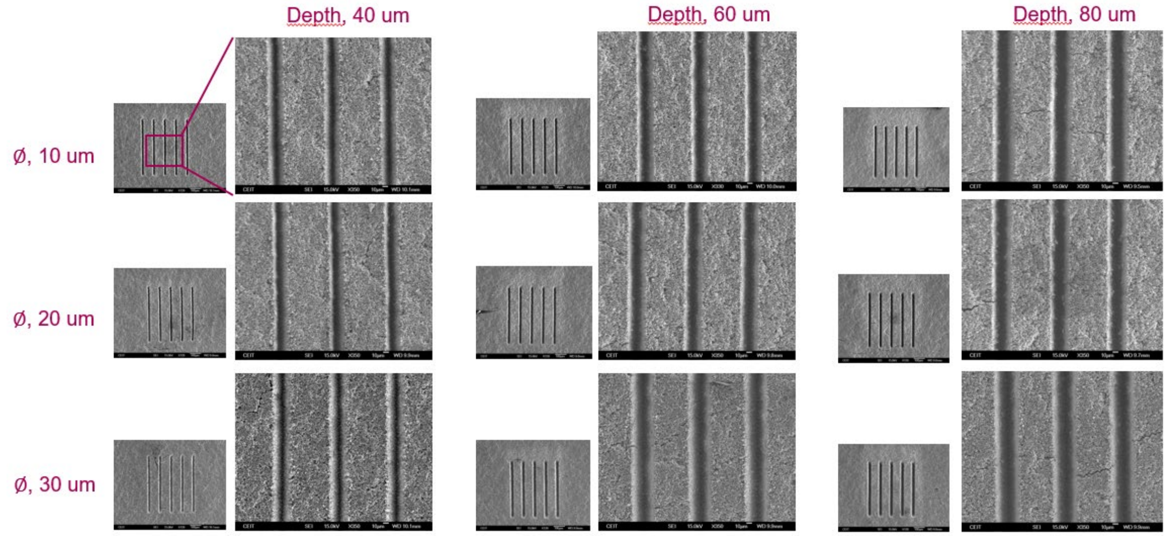

Fig. 2. SEM images of processed trenches

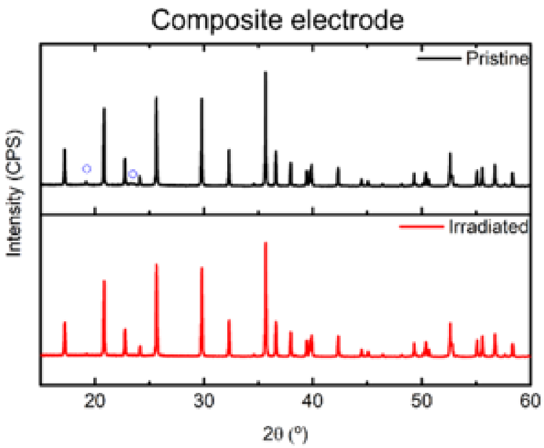

Fig. 3. XRD analyses of pristine and irradiated electrodes

The SEM images do not show any melting or redeposition on the trench edge due to laser processing. There is also no evidence of damage to the surface of the electrode. XRD analysis does not indicate any change in the crystalline structure of the active material (LFP) or in the particle size of the composite electrode.

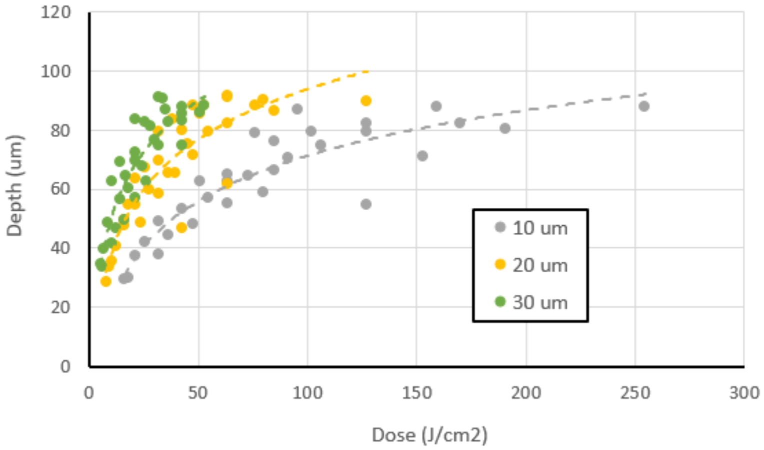

Fig. 4. Trench depth versus irradiation dose

Comparing the trench width obtained for different beam sizes, no significant differences are observed between electrodes processed with a 10 um and a 20 um beam, while the 30 um beam generates wider trenches for the same depth. Comparing the width obtained for different trench depths, the deeper the trench, the wider the width. Again, this is more evident for the largest beam size.

The images captured by the optical profiler show that the range studied for beam power and scanning speed allows processing trenches as deep as the electrode thickness (90 um), the depth obtained depending on the beam size and the irradiation dose. As expected, the relationship between trench depth and dose fits a logarithmic equation for a fixed beam size. The larger the beam size, the deeper the trench obtained for the same dose. Easier evacuation of the material removed, due to the formation of wider trenches, explains the latter result.

4. Conclusions

It has been demonstrated that electrodes can be easily structured by laser processing. The ability to process deep 3D structures without damaging the electrode surface or altering its composition has proven the suitability of femtosecond laser technology for structuring thick composite cathodes of solid-state cells.

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