Optimization of characteristics of laser-processed metal/semiconductor surfaces for sensor application

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Introduction

We elaborate the formation process of femtosecond laser-induced periodic surface structures (LIPSSs) on metal (Ag, W), semiconductor (Si) and dual metal-semiconductor (Au-Si) surfaces for sensor application. The laser irradiation parameters stipulate certain characteristics of processed surface, i.e. the scale and direction of the LIPSSs, periodicity perfectness, depth, width, and micro-roughness of the LIPSSs, etc. Different methods of the characterization of laser-treated surfaces and byproducts of texturing (especially, ablated nanoparticles (NP)) help to find the ways of the optimization of crucial parameters of the processed surfaces.

Method of LIPSSs fabrication

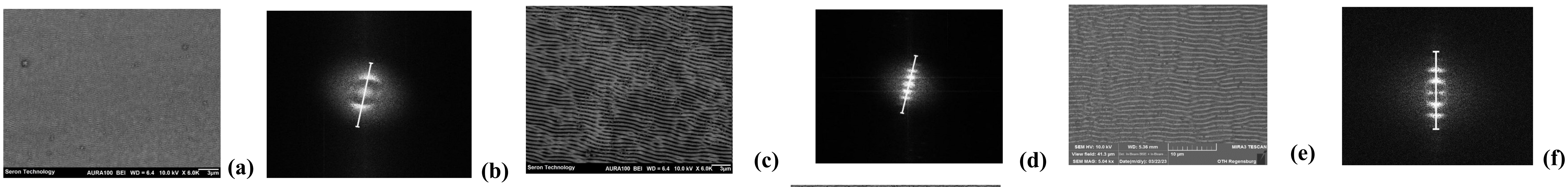
LIPSSs were formed with the impact of femtosecond laser radiation (wavelengths 400, 800, 1300 nm, pulse duration of ~ 130-150 fs at the repetition rate of 1 kHz with a mean power in the range of 0,1-1 W) in the multi-pulse regime in air.

Methods of the characterization of laser-treated surfaces

- Scanning electron microscopy (SEM) with subsequent 2D Fourier transform of SEM images of the laser-processed surfaces reveal the deviations from periodicity, the presence of NPs and other features on the surfaces of the studied materials.
- A real-time monitoring of the LIPSSs formation based on the measurement of the emission from semiconductor (in particular Si) during its laser structuring indicates the quality of the formed LIPSSs*
- The measurements of time-resolved emission from the surface under structuring monitor the features formed during laser structuring.

Results

- **SEM analysis** reveal the compliance with the periodicity of LIPSSs on W under different irradiation wavelengths, presence of additional periods or features under wavelengths of 400, 800 and 1300nm (Fig. a – f). SEM images of Ag surface treated with a femtosecond laser with a wavelength of 800 nm (g) and 1300 (h, i) demonstrate a noticeable difference in homogeneity across the entire stripe, number of ablated NPs on the formed surface (see Fig. 1, g – i). SEM analysis can be used to optimize the processing of Ag samples.



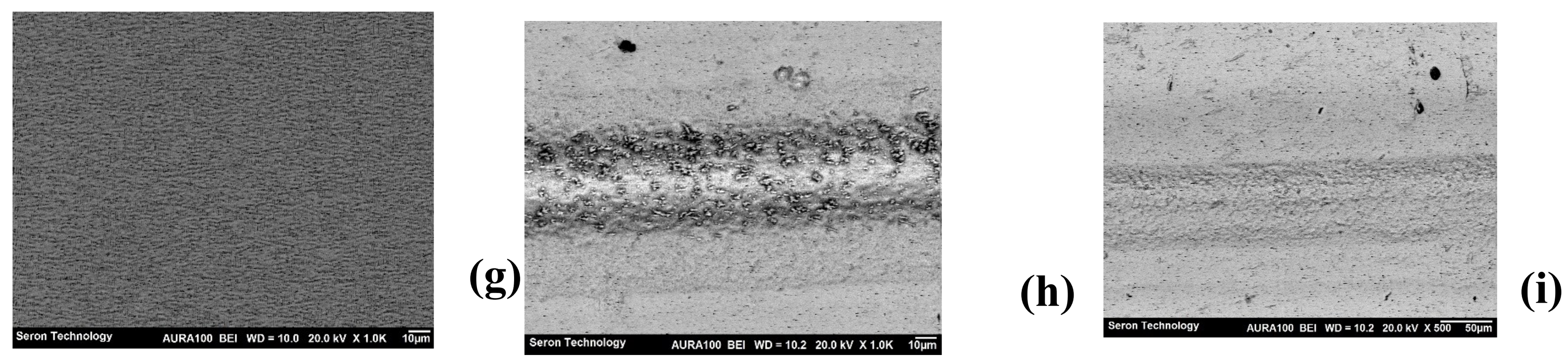
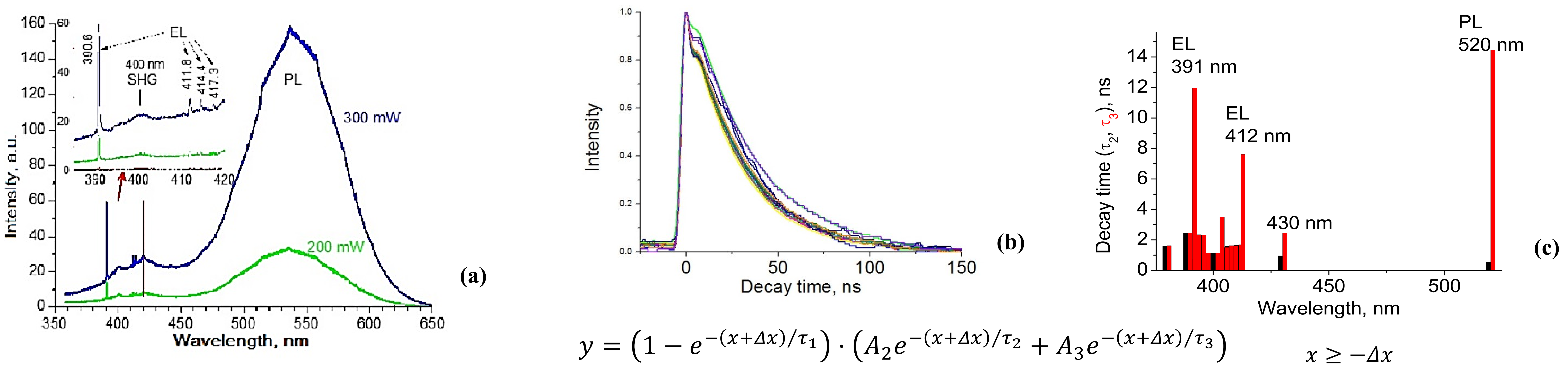


Fig. 1. (a) SEM image of the W surface treated with a femtosecond laser with a wavelength of 400 nm, (b) 2D Fourier transformation of SEM images (a), processing with a wavelength of 800 nm (c)), (d) 2D Fourier transformation of SEM images (c), (e) processing with a wavelength of 1300 nm, (f) 2D Fourier transformation of SEM images (e); SEM images of Ag surface treated with a femtosecond laser with wavelengths of 800 nm (g) and 1300 (h, i)

- **The measurement of emission during structuring** demonstrate that the intensity ratio of the second harmonic generation (SHG) on the modified Si surface to the sharp emission lines (EL) of the ablated Si atoms and ions indicates the quality of the formed LIPSSs (see Fig 2, a)*.
- **Time-resolved emission analysis** (Fig. 2, b) allows to evaluate the impact of different species that take part in the emission from the sample during laser structuring (see Fig. 2,a). The diagram at Fig 2, c, show the characteristic decay times for emission of neutral and ionized ablated Si atoms (391 - 412 nm), silicon oxides (around 500 nm) longer than 2 ns, and shorter decay times are typical for emission of ablated Si NPs that partly cause the broad background.



$$y = \left(1 - e^{-(x+\Delta x)/\tau_1}\right) \cdot \left(A_2 e^{-(x+\Delta x)/\tau_2} + A_3 e^{-(x+\Delta x)/\tau_3}\right) \qquad x \geq -\Delta x$$

Fig. 2. (a) The emission spectra from a moving Si sample during femtosecond laser treatment, (b) decay times curves for the the emission from the Si sample, (c) diagram of decay time distribution versus wavelengths

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CONCLUSIONS: The proposed specific methods for the characterizing laser-treated surfaces allow to evaluate the quality and dimensional parameters of obtained texture after femtosecond laser processing, provide real-time diagnostics of the structuring, to draw a conclusion about the influence of various species on the emission from the sample

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