Ph.D. thesis referee report

Title: Modification of bandgap materials by ultra-short laser pulses

Author: Ing. Juraj Sládek

The topic of the Ph.D. thesis is actual. Laser surface texturing of materials is a topic intensively studied in the research laboratories for many years. A lot of work was already done, as mentioned also by the author. The work is well focussed on the not yet fully analysed area of semi-transparent materials and production of laser induced periodic surface structures (LIPSS) on them and with high quality and homogeneity on large areas.

The thesis is well structured. At the beginning there is a nicely and clearly written description of present state of problematics of laser-material interaction and LIPSS. The main focus is given to semiconductors and dielectrics. The next chapter presents experimental methods and equipment. It is well written and contains also many practical hints for future students learning the topic. After that, results are presented. And at the end the work is concluded with some outlook to future works.

The thesis is a good combination of experimental approach and theoretical background. A lot of experiments were done and the results are well structured and presented. I want to point out nice presentation of formed surface structures in the fluence-overlap maps in Figs. 39 and 44. The results are also summarized by empirical fitting functions. During the work, significant technical development was done to be able to well analyse the results, like automatic laser spot evaluation or DLOA image analysis. The experimental methods were appropriately chosen and executed.

The text is well written and contains only very low amount of mistakes, e.g.:

- The “n” in the Eq. (3) should probably contain also subscript “e” -> “n_e”.
- In the legend to Fig. 8 on page 22 is mentioned “uppermost graph”, but it is on the right, not on top.
- In Fig. 38 (page 62), a scale is missing in the figures and also the 0° image.
- LIPSS period Λ is not in the list of symbols and it is not explained how the aspect ratio (Λ/depth, page 77) is calculated.

Remarks to the text and structure:

- Sentences like “I designed …” (pages 93, 55) or “my experiments” (page 63) does not seem to me appropriate. Better would be passive voice “… was designed”.
- It is also a bit strange to read several times “These results are prepared for a publication”. For me it is obvious that some results from a thesis will be later published.
- On pages 30-32 in the Experimental methods (section 2) is a lot or text which would probably fit more to the description of the state of the art (section 1).
- Some graphs are not given in fluence but in power (Fig. 62) or not in overlap but in pulse spacing (Fig. 67), which is then more difficult to compare with the others.

The discussions about influence of precise laser spot positioning either by scanner or sample movement are important, but in fact not very relevant to the industry, in my opinion, because the nowadays commercial laser micro-processing machines are developed to even better precision, only for certain price.

The thesis yielded interesting results for both laser science and technology, e.g.:

- Visualisation methods of different structures and their analysis methods
- Influence of wavelength on ablation and LIPSS formation on bandgap materials
- Influence of spot size, pulse duration, polarization orientation and defects on homogeneity of LIPSS formation in scanning process and proposition of explanations and physical principles acting there
- Parabolic functions for prediction of resulting structures on silicon in the fluence-overlap space
- Influence of spatial beam profile – particularly the unexpected inconveniences with the flat-top beam
- Formation of homogeneous LIPSS stripes and understanding the formation process
- Parameters for formation of LIPSS on Silicon with high level of homogeneity on large surfaces
- Discovery of complex structures produced by cylindrical lens beam shaping and scanning

In general, the theses level is very good. The Ph.D. thesis goals were fulfilled.

In this work, Juraj Sládek has shown its capability of doing complete experimental scientific work from concept and methodology through performing experiments and analysing results to writing and discussing results.

Based on this, I strongly recommend the Ph.D. thesis to the defence.

doc. Ing. Jiří Martan, Ph.D.

Referee

14th June 2023

Questions:

1. On pages 60 and 61 (Tab. 10), there are determined nonlinear processes (MPI, TI) probably involved in the ablation. What is this knowledge good for? Does it correlate with some results?
2. What was the pulse repetition frequency used for production of structures shown in Fig. 38? Can there be significant heat accumulation effects from previous laser pulses?
3. The results using cylindrical lens (Fig. 65, page 91) are interesting, but performed only at one-line scanning. Do you think that the non-homogeneity of the structures would be eliminated or decreased when scanning bigger surface with overlapping of lines (as was done for Gaussian beam)?
4. The study of multiphoton modification in the Mid-IR (section 5) is interesting. How fast was the detector? Was there ablation present during the process? Can the measurement be affected by the particle or plasma shielding or emission?