

Three-dimensional laser writing deep inside Gallium Arsenide

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Volume laser inscription (VLI) inside materials have been widely investigated because of its unique possibility to create precise and functional 3D microstructures under the surface. Recent years witness an increasing interest of shifting similar applications from dielectric materials to more challenging semiconductors that have different material properties (Fig. 1a). In particular, much stronger nonlinear propagation effects are expected that can strongly distort the laser focus conditions when working deep inside the materials (Fig. 1b) [1]. Recently, tremendous efforts have concentrated on silicon (Si), the basis material for electronics industry. However, there are so far very few works on the specificity of other important semiconductors, especially Gallium Arsenide (GaAs) which also has important applications in electronics sector such as integrated circuits, light-emitting diodes and photovoltaic cells. GaAs has very different properties compared to Si. GaAs exhibit a direct bandgap of 1.44 eV whereas Si has an indirect bandgap of 1.12 eV. The nonlinear refractive index of GaAs is also more than 5 times higher than the one for Si. These and other differences must lead to significant differences for the VLI conditions.

In this work, we first systematically investigate the successful VLI conditions by using different pulse durations (from fs to ns) and the focusing conditions (NA from 0.3 to 0.85). These results must serve as an important guideline for future application of VLI inside GaAs. The modification results in GaAs by different pulse duration using a NA0.85 lens are illustrated with Fig. 1c. The results indicate a strong dependence of pulse duration to obtain successful VLI. Besides this similarity to Si case [2], we also observe some differences. First, we find that 21-ps laser pulses will lead to longer and less stable modifications than Si. This could be well explained by the low threshold of self-focusing/filamentation phenomena for GaAs due to its high nonlinear refractive index. Second, compared to Si, we observe nearly 10 times smaller damage threshold with 5-ns laser pulses using same conditions. The underlying mechanism behind this response can be discussed in terms of absorption efficiency depending on the bandgap structure on the basis of this comparison between GaAs (direct) and Si (indirect).

Inspired by observed dependencies of the modification results to the pulse duration, we also explore the possibility to use THz-repetition-rate ultrafast laser burst that allows accumulation of free-carriers and heat between pulses [3]. Sub-picosecond delay between pulses is enabled by thin birefringent crystals that create different optical paths between polarisation components of the pulses. By using multiple crystals with different thicknesses, more than 64 pulses can be obtained with ~ 200 fs inter-pulse delay. The burst-induced plasmas inside GaAs are monitored by our recently developed method that uses the luminescence from the irradiative band-to-band recombination [4]. We report on the possible optimizations from this burst accumulation strategy on the basis of these measurements and discuss its potential for fabricating 3D structures beneath the surface for electronic or photonics applications.

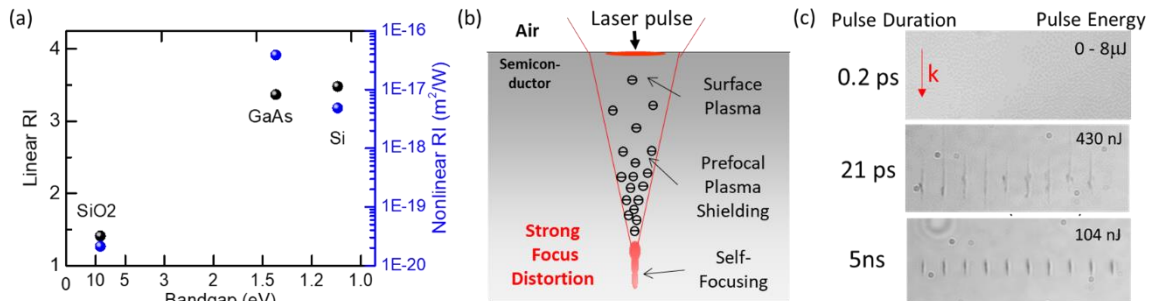


Figure 1. (a) The comparison of material properties between SiO₂, GaAs and Si. RI represents refractive index. (b) Typical phenomenon that influence the laser focusing process inside GaAs. (c) Modification results obtained for different pulse durations (NA=0.85).

Acknowledgement: This work is funded by H2020 European Research Council (724480).

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