

Ultra-High Space-Time Localization of Laser Energy for 3D Fabrication inside Semiconductors

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3D fabrication of semiconductor device is important for numerous advanced applications from integrated microelectronics/photronics to micro-electro-mechanical systems (MEMS). Direct laser writing creates a promising alternative to lithographic methods requiring tedious steps. This relies on the possibility to penetrate inside the materials with ultrashort laser pulses in the infrared region of the spectrum to precisely induce micro/nano-scale structures. However, recent research [1-3] shows severe difficulties specific to semiconductors. The narrow bandgaps and large nonlinear refractive indices cause strong limitations on the achievable focusing conditions as well as important nonlinear propagation effects opposing to the high space-time energy localization required for precise and controllable fabrications [3]. Accordingly, there is a strong motivation to monitor and optimize the applied laser conditions inside semiconductors to achieve high-quality 3D fabrication inside semiconductors.

In this research, we first monitor the laser propagation and distortions inside semiconductors (e.g. Gallium Arsenide) arsenide by imaging the fluorescence signal resulting from carrier recombination in the laser ionized area. The setup is shown in Fig. 1(a) and a typical result obtained for a 200-fs pulse is shown in the first image of Fig. 1(b). The validity of this method for quantitative measurements is verified in our previous publication [3]. We observe a highly asymmetric shape of the ionized area, which indicates strong energy deposition before and across the focus. With measurements at different pulse energy levels, we find that the plasma exhibit a saturation in the growth of the carrier density under increasing applied intensities. This evidences a severe clamping of the intensity that can be delivered in the semiconductors, an effect much stronger than what is widely observed in wide bandgap dielectrics. Even with a very high incident pulse energy, it is sticking to mention the incapacity to achieve modification with repeated femtosecond pulses in these studied conditions.

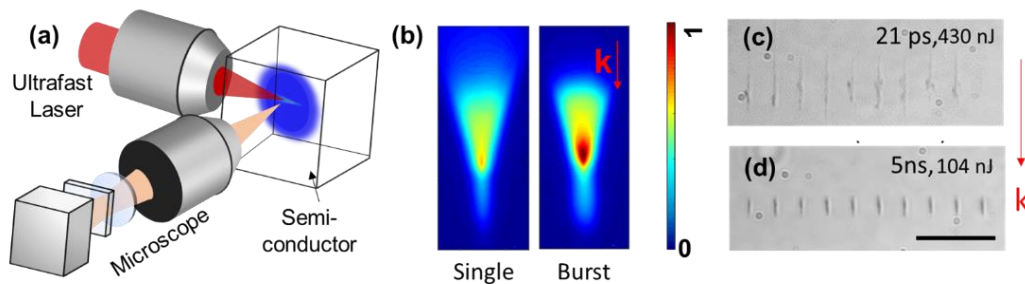


Fig. 1 (a) The experimental setup for measuring the fluorescence from the plasma recombination inside GaAs. (b) The comparison of plasma fluorescence results between the unshaped single pulse and the burst result of 64 pulses. A clear better energy localization is obtained by the shaping effect. (c-d) The fabrication results obtained by the using longer pulses of 21 ps and 5 ns.

To address this problem of energy delivery, we investigate different approaches for higher localization of the pulse energy. To circumvent plasma screening and other detrimental nonlinear propagation effects, we shape the applied ultrafast pulses temporally or spatially so that we expect to work with reduced power and intensities in the pre-focal region. Temporal shaping for, for instance burst-mode irradiation gives a direct way to reduce the peak intensity while maintaining the energy level [1-2]. Using spatial beam shaping we introduce compensation measures to the encountered wavefront distortions caused by nonlinear propagations. The degrees of optimization are verified by the above mentioned imaging method in light-emitting semiconductors. An example of measurements is shown in the second image of Fig. 1(b). In comparison to a single pulse irradiation, much-improved energy localization is demonstrated using an ultrafast train of pulses with the same applied energy. Benefiting from these optimizations, permanent modifications become achievable, as shown in Fig. 1(c-d). The successful fabrication of internal structures may open wide possibilities to fabricate 3D functional devices inside semiconductor materials.

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References

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