Carrier Dynamics Of All-optical Light Modulator Using Wide Bandgap Semiconductors For Area Printing®

Selim Elhadj[1]

[1]Seurat Technologies, 255 Ballardvale St, Wilmington, MA 01887, USA

Abstract

An all-optical addressed semiconductor-based spatial light modulator (SLM), or "light valve", is used for dynamic laser beam patterning in metal additive manufacturing Area Printing® [1]. The light valve spatially patterns high power laser pulses delivered to a metal powder bed to produce near-net shape, fully dense metal parts. One of the enabling technologies uses wide-bandgap semiconductors that act as programmable switches that are optically addressed via bitmap photoexcitation images. The focus of this computational study is to model the dynamics of photo-switchable semiconductors and their photoelectric modulation to optimize semiconductor materials for Area Printing pattern switching.

Photoexcitation with energies below and above bandgap energy result in complex carrier dynamics that control SLM device performance, rise and decay switching speed, patterned beam spatial resolution, and contrast achieved, all key parameters of the metal Area 3D Printing process. Wide-bandgap materials are especially well suited for this emerging industrial application due to their high breakdown voltage, optical properties, and the improving availability of high-quality commercial wafers. Still, gaps exist in the understanding of such semiconductors for photoelectric modulation and switching at MW to kW levels.

The carrier dynamics driven by light photoexcitation are coupled to an equivalent model circuit of the drive voltage on the SLM device coupled to a finite element simulation of the semiconductor response within the device structure. Beyond the materials properties from the COMSOL materials library, we complement the model materials properties inputs with measured carrier electronic transitions. We experimentally probe the optoelectronic properties of the semiconductors via optical-deep level transient spectroscopy [2], or temperature-dependent capacitance transients measurements to resolve activation energies, electron- and hole-capture cross sections for each trap, and densities of deep and shallow trap levels. Defect related traps control several excitation and relaxation pathways that depend on the levels of optical injection of carriers and recombination pathways. Parasitic laser absorption in the semiconductors imposes further device-level constraints that we characterize temporally and spatially via coupled multiphysics finite element analysis of the thermal response when the device is exposed to high laser power. We thus highlight key areas of wide bandgap semiconductor properties challenging the performance capabilities in optically switched devices used in high power applications.

Reference

[1] https://www.seurat.com/area-printing

[2] Lang, D. V. (1974). "Deep-level transient spectroscopy: A new method to characterize traps in semiconductors." Journal of Applied Physics 45(7): 3023-3032.