Defect engineering of diamond by ultrashort laser for optoelectronic applications

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Defect engineering applied to wide bandgap semiconductors will be extensively exposed. Wide bandgap semiconductors are well known for the extreme physical properties, enabling operations in harsh environments, and for the capability to host defects with quantum characteristics. However, these materials allow negligible interaction with optical wavelengths. The defect engineering consists of the local introduction of defects in the crystal lattice under highly nonlinear conditions, induced for example by ultrashort laser pulses [1], to tailor the optical and electronic properties of such materials.

The first result of the defect engineering strategy is black diamond, namely a semiconductor with greatly improved optical and photoelectronic properties while maintaining outstanding charge transport capabilities and mechanical properties, typical of transparent diamond films. Black diamond films are obtained by a controlled nanoscale periodic texturing on the diamond surface, performed by means of ultra-short pulse laser. It represents a technologically easy process to fabricate structures on diamond surface with a periodicity ranging from tens to hundreds of nanometres, directly depending on laser wavelength and on average number of pulses. The periodic nanostructuring is able to drastically modify the diamond interaction with solar radiation from typical optical transparency up to solar absorptance values even close to 99% and to induce an enhancement of photo-responsivity in the visible range up three orders of magnitude larger than the starting transparent diamond film [2,3]. By disentangling the optical absorption enhancement from the electronic increased density of states within the diamond bandgap, it results that introduced defects act as defect bands. The control of the defect nature as well as its density and energy position is fundamental to control the resulting photo-electronic properties.

Ultrashort laser pulses are also useful to induce chemical transformation in the bulk of transparent crystals, thus allowing the creation of paths for transport of light and charge carriers [4], and to produce hyperdoped zones containing spin-correlated defect complex centres [5], characterized by coherent radiation emission and room-temperature entanglement capability [6]. All these technological concepts can be integrated for future efficient high-temperature solar cells [7] and for optoelectronic platforms suitable for quantum information, communications and/or sensing.

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