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Research and development of femtosecond-laser hyperdoped silicon

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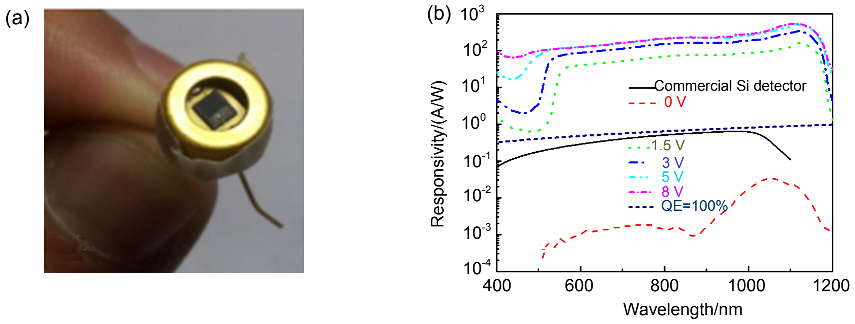

Picture of photodetector (a) and (b) responsivities as a function of applied bias voltage for a sulfur-hyperdoped silicon photodiode.

Abstract: Silicon one of the most abundant elements in the earth's crust has a large impact on modern industry. It is an extremely versatile material with various applications ranging from solar energy to electronic devices. After decades of process, the crystalline silicon solar cell has been successfully commercialized all over the world due to its low cost and high efficiency. As the fundamental component of integrated circuits, silicon-based chips have shown outstanding performance in computers and cell phones. Surprisingly silicon is also a promising host material for the new generation of quantum devices owing to its excellent properties of spin. Definitely it is the core material and classical platform among various materials in the world. However, there are still some blocks which limit its applications, eg. The bandgap of crystalline silicon is only 1.12 eV (~1100 nm), which prohibited the usage in far-infrared range. The carrier mobility of silicon is not high enough, which limited performance of electronic devices.

Benefiting from the rapid development of ultrafast laser, those constraints mentioned above could be resolved by interaction between femtosecond laser and silicon. Femtosecond laser pulses induce intriguing transient photochemical reactions with semiconductors at the surface, owing to its ultrafast duration and ultra-high intensity. Taking advantage of these characteristics, material is effectively doped. The doping level is likely far beyond the solid solubility limit (so called supersaturated doping), in the meanwhile quasi-periodic structures with micro-/nano- scales are created at the surface of material as well. As a result, surface properties are strikingly changed, e.g. ultra-high absorption over a broad range from near ultraviolet to infrared emerges, which breaks the limit of traditional physics and brings novel applications. The excellent properties of this modified silicon material tap more potentials in the silicon-based semiconductor industry. In addition, compared with ion implantation, femtosecond hyperdoping can reduce lattice defects, and improve supersaturated substitution doping.

In this review, we summarized the ultrafast dynamics of the interaction between femtosecond laser and silicon and the physical mechanism of supersaturated doping. Based on the typical TTM (two-temperature model), the Drude model was introduced to correct the surface reflectivity, and a two-dimensional TTM-Drude model was proposed to explain the ultrafast energy transfer process. Subsequently, a competitive model was established that led to LIPSS (laser-induced periodic surface structures) formation on the silicon surface. Meanwhile, the microscopic process and physical mechanism of femtosecond laser supersaturated silicon doping had been improved through the researches of the plasma plume in silicon etching. Finally, we also introduced its applications in relevant areas, such as photoluminescence and photodetectors and depicted future prospects of femtosecond laser hyperdoped and modified silicon.

Keywords: hyperdoping; femtosecond laser doping; femtosecond laser processing; silicon

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