

Delta-Doping in Silicon by Argon Ion Pre-implantation and Nanosecond Laser Annealing

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Abstract : Delta-doping (δ -doping) has extensive applications in advanced metal oxide semiconductor field effect transistors, quantum devices and deep ultraviolet photodetectors. In this work, we demonstrate a novel method to form high-concentration phosphorus δ -doping in silicon with the assistance of argon pre-implantation and nanosecond laser annealing. It is encouraging that argon pre-implantation dramatically increases the incorporation of P dopants by 1-3 orders of magnitude, depending on the dosage of argon pre-implantation. The δ -doping layer in silicon has a peak phosphorus concentration of $1.44 \times 10^{20} \text{ cm}^{-3}$. Hall measurements reveal that the argon pre-implantation significantly increases the electron concentration, resulting in metallic-like conductivity in the δ -doping silicon layer. The magnetoresistances of the δ -doping samples decrease as the perpendicular magnetic field increases due to the weak localization of electrons, which implies the formation of a two-dimensional electron gas. As a demonstration, a highly sensitive deep ultraviolet photodetector is fabricated by forming an n-type δ -doping layer on a p-type Si substrate. A photocurrent of $0.33 \mu\text{A}$ is generated in the fabricated deep ultraviolet photodetector under the illumination of light at a wavelength of $\lambda = 280 \text{ nm}$ and the intensity of $266 \mu\text{W}/\text{cm}^2$, showing that the responsivity of the device is 0.124 A/W , two times of a commercial Si photodiode (LSSPD-U1.2, Beijing Lightsensing Technologies Ltd). This combination of argon pre-implantation and laser annealing offers a promising route for the realization of δ -doping layer in silicon, with potential applications in a variety of electronic and optoelectronic devices, including high-speed transistors, photodetectors, and quantum devices.

Keywords : argon pre-implantation, delta doping, laser annealing, two-dimensional electron gas

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