Laser direct writing in wide bandgap semiconductors for advanced interconnect and gas sensor applications

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Abstract

A direct conversion technique is demonstrated to produce highly conductive tracks on silicon carbide by irradiating it with a laser beam. It is found that laser irradiation of insulating silicon carbide substrates decreases its resistivity from 10^{11} to 10^{-4} Ω-cm. Atomic force microscopic images of the tracks indicate the conversion of larger structures into smaller, more round-shaped structures suggesting the formation of globules. However, laser irradiation of silicon carbide conductors in the presence of pure oxygen transforms the conducting track into an insulator. Nanosecond pulsed Laser Direct-Write and Doping (LDWD) technique is used to heat an epilayer, which was a single crystal 4H-SiC layer, below its decomposition temperature for *in situ* fabrication of nanoribbons. High resolution transmission electron microscope and electron diffraction pattern revealed that the nanoribbons have graphene-like crystalline hexagonal structure. These graphene-like structures are formed inside the epilayer in three layers each being approximately 50-60 nm wide, containing 15-17 individual sheets. The layers are self-aligned and they extend parallel to the (000l) plane of the SiC epilayer with their c-axis perpendicular to the incident laser beam. The process can be modified to create carbon rich surfaces and embedded carbon regions, particularly graphene, using multiphoton photolytic laser processing on or in silicon; carbon dopants are used. Graphene can also be formed on silicon carbide by the photolytic process provided the silicon carbide structure/chemistry is transparent to the processing laser wavelength. High pressure laser implantation (HPLI), where precursor pressure exceeds 500 psi ($3.4x10^6$ pa), enhances nitrogen dopant solubility in silicon carbide resulting in dopant concentrations greater than 4.8×10^{20} atoms per cubic centimeter at a depth greater than 1 micron. HPLI has promise for improved doping of gallium nitride substrates with magnesium and the amphoteric dopants carbon and silicon. The LDWD process is expected to revolutionize the future of nanodevice fabrication with nanoscale interconnects for high temperature and high power electronic and optoelectronic applications using SiC. This process is demonstrated to produce doped tracks of lower electrical resistance on polycrystalline and single crystal SiC substrates. The selective-area doping is a mask-free process that can be utilized to produce various patterns of doped regions for novel device architectures. Using this doping technique, uncooled SiC-based gas sensors are produced and these sensors yield optical signals instead of electrical signals generated by conventional sensors. P-type dopants Ga, Sc, P and Al are incorporated into an n-type crystalline 6H-SiC substrate by a laser doping technique for sensing CO_2, CO, NO_2 and NO gases, respectively.