Electronics Properties of GaAs Crystals Containing Deep Nanoclusters

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In this work the role of deep centers in changing of the material properties and structures based on it is shown using an example of gallium arsenide compensated with deep impurities. The transition elements of the iron group create states in the band gap of the A^3B^5 crystal that are mainly determined by the atomic d- or f-states of the impurity. The use of semiconductor materials with d-impurities (GaAs <Cr>, GaAs <Fe>) in solid-state electronics is based on two specific effects.

The first one is connected with compensation. If there are small donor (N_d) and deep acceptor (N_t) impurities in A^3B^5 structure in the ratio of $N_t > N_d$, then electrons of shallow donors compensate the site level d-impurities. For example, in a GaAs <Cr> system, Cr diffuses as an interstitial atom. Meeting the gallium vacancy $Cr_i + V_{Ga} \rightarrow Cr_{Ga}$ chromium becomes fixed in a gallium site in a tetrahedral environment of arsenic ligands. The material with such double doping will be of extreme high-resistance: for $N_t > N_d$, the high-resistive layer will have a p-type conductivity, and for $N_d > N_t$, the donor center electrons will completely compensate the site level d-impurities and high-resistive layer has n-type conductivity.

The second effect is due to the random nature of the distribution of impurity atoms in the crystal. Since in a single thermodynamic system (a crystal) the level of the chemical potential aligns, the band picture acquires a corrugated shape. As a result, the electrons and holes in their zones are spatially separated by potential barriers to direct recombination, and the lifetime of the nonequilibrium carriers (τ) increases according to the law: $\tau = \tau_o \cdot \exp(\Delta E/kT)$, where τ_0 is lifetime in the material before alloying; ΔE is the average value of the barrier height for recombination. The effect of a giant increase of the lifetime can be observed only in strongly compensated material. Thus, in the GaAs <Te, Cr> system the recombination barrier value is of $\Delta E \cong 0.15$ eV, and the lifetime at 300 K increases up to ~ 0.1-1 μs.

By varying the type of doping impurities, as well as the doping level and the impurities‘ concentration gradient, it is possible to modify the electrophysical characteristics and properties of the high-resistive layers within a wide range, e.g. a reduction of the GaAs electrical conductivity to a value smaller than intrinsic one and an increase of carriers lifetime up to 0.1 μs. The control of the deep impurity centers recharging process makes it possible to create an element base for micro-opto- and functional electronics, which outdo known analogs in the aggregate of parameters. With the use of high-resistive GaAs<Cr>, GaAs<Fe> structures a series of original semiconductor devices was created, with a set of basic characteristics exceeding the known analogs: ultrafast electronic switches, photodetectors and ionizing radiation detectors.

Industrial models are designed and created electronic controlled keys, S-diodes and S-diodes with the control electrode used in a power pulse engineering to form larger voltage drops up to 1 kV and current up to 100A during 40-200 ps and a rate of operations up to 1 MHz. Devices are efficient as shapers in passive relaxation oscillator mode and intensification mode.

Photodetector elements of the visible and UV spectral range with a threshold sensitivity of 10^{-15} W/Hz$^{1/2}$ in the spectral range of 0.2-0.4 microns are designed.

In collaboration with world leaders in the field of collider experiments (LHC, ILC and others.) and synchrotron radiation (DESY, ESRF, PSI, RAL, BNL, JINP et al.) matrix detectors of large area, 84,6x28,2 mm^2, are developed at TSU. A number of single elements is up to 1 million pixels and matrix sensors are designed to detect single photons of synchrotron radiation, and can be used in high-energy experimental physics, in medical, scientific and industrial systems of digital color X-rays and gamma rays images.