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Study of carrier density depth profiling in highly-doped Ge using HREELS

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The transport characteristics of the free carriers in semiconductor materials determine the functional behavior of devices. Germanium (Ge) is one of strong candidates for replacing silicon (Si) in complementary metal oxide semiconductor (CMOS) due to its higher carrier mobility. As scaled down to nanometer in size, understanding of the carrier density profile in near surface to achieve performance of devices.

In this work, we present the carrier density depth profile in near surface region for epitaxially grown highly-doped n-type Ge on intrinsic Ge/Si substrate with Cl-termination using high resolution electron energy loss spectroscopy (HREELS). An n-type Ge (6×10^{-4} Ωcm) epi-layer was treated by HCl to remove native oxide and to terminate the surface with Cl. After this chemical treatment, samples were loaded into ultra-high vacuum chamber (~10^{-8} Pa) to measure HREELS spectra. The incident energy change in HREELS allows us to obtain a tunable probing depth and the observed plasmon energy is proportional to the free carrier density. This enables us to evaluate the carrier concentration profile in depth [1, 2].

Figure 1 shows the HREELS spectra of P-doped Ge at two different incident energies (2 and 80 eV). Molecular vibration mode of Ge-Cl was found at ~51 meV and hydrocarbon contamination trace was detected at ~180 meV. Plasmon mode was also observed at 106 and 133 meV for the incident electron energy of 2 and 80 eV, respectively. This plasmon peak change in its position means that the carrier density is different in depth. Figure 1 shows that the plasmon peak becomes dominant as the incident electron energy increases, whereas the intensities of the surface molecular vibration peaks relatively become weak.

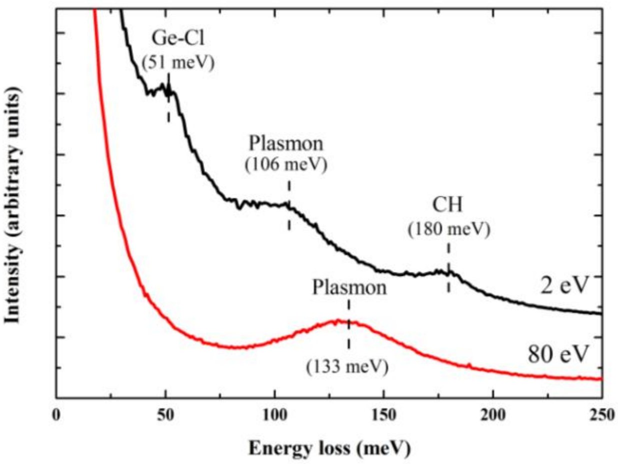

Figure 1. HREELS spectra at different incident electron energy (2 and 80 eV) for P-doped Ge after HCl treatment.

This carrier density depth profile is plotted in Figure 2. It is found that the low carrier density region forms 9.2 nm deep from the surface and the carrier density becomes almost saturated with 3.25×10^{19} cm^{-3}.

We have demonstrated that HREELS technique can be used to characterize the depth profile of carrier density in near-surface region (< 30 nm).

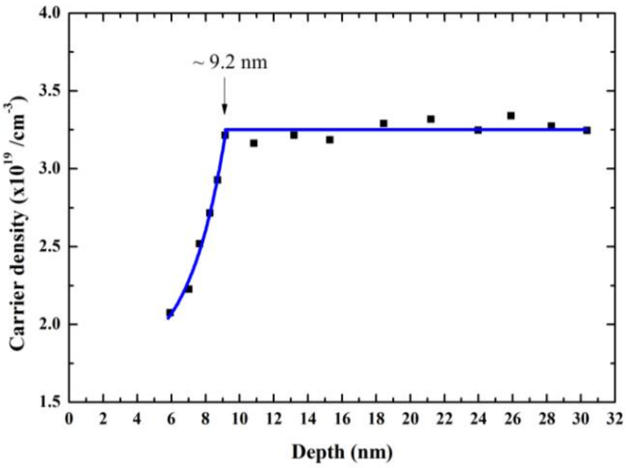

Figure 2. Carrier density depth profile for P-doped Ge with Cl-terminated surface. The solid line is plotted for a guide to the eye

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