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KPFM Imaging of Donor Clusters in Selectively-Doped SOI-FET

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Introduction

Tunneling transistors based on single dopants working as a quantum dots (QD) have been recently studied as breakthrough technique for miniaturization [1, 2]. For such devices, precise control of dopant arrangement inside the channel is crucial and requires relatively complex fabrication methods [3]. We challenge a new approach for dopant-based device fabrication based on CMOS compatible selective doping technique. The process leads to formation of donor clusters inside doped areas. Clustered donors [4] can work as localized QDs in the channel, allowing single electron tunneling. By using Kelvin Probe Force Microscope (KPFM), which has ability to resolve individual dopants [5], clusters of a few P donors are identified and characterized as a function of depleting gate voltage.

Selectively-doped SOI-FETs

Investigated devices are SOI-FETs with ultra-thin top oxide layer (~2 nm) and substrate-Si working as back gate (V_{sub}) to allow proper KPFM measurement. Channel has thickness, length, and width of 20, 1000, and 500 nm, respectively. Doping was done by thermal diffusion from spin-coated phosphorus source through 200-nm-wide slits opened in oxide layer by electron beam lithography. In this work channel was selectively doped with $N_D = 4\times10^{19}$ cm^{-3}.

Results of KPFM measurements

Measurement setup is shown in Fig. 1(a). Imaging was done at room temperature (T = 300 K) under high-vacuum (p = 10^{-7} Torr). Different bias (V_{sub}) was applied to substrate (0 to -6 V). Potential depth versus V_{sub} was measured to confirm channel depletion. Step-like characteristic of barrier height implies depletion above V_{sub} = -3.5V (Fig.1 (b)). Figs. 2(b-c) show results of imaging of one doped slit. For V_{sub} = 0 V (Fig. 2(b)), contrast is weak since dopants are screened by the electrons in the channel. Potential modulation comes from work-function differences. For V_{sub} = -4.0 V (Fig. 2(c)), contrast is increased. Deeper-potential area (marked in Fig. 2(c)) can be ascribed to a large dopant cluster surrounded by flatter potential of uniformly distributed dopants. In summary KPFM images show: (i) deepening of doped area potential due to electrons depletion by applying V_{sub} > -3.5V; (ii) local modulation of potential for V_{sub} > -3.5V, due to multiple-donor cluster formation inside doped area in result of selective doping technique.

Conclusions

Presented KPFM observation validates selective doping technique and provides useful information about the formation and distribution of donor clusters.

References

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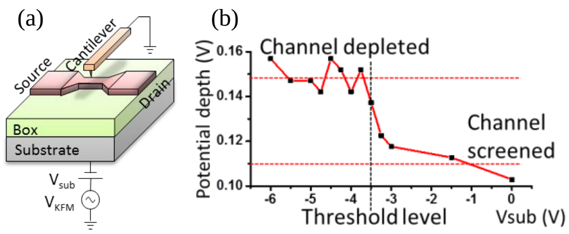

Fig.1 (a) KPFM measurement setup – source and drain are virtually grounded. (b) Potential depth of the doped area B in relative to non-doped area A (along yellow line as shown on Fig.2) as a function of V_{sub}.

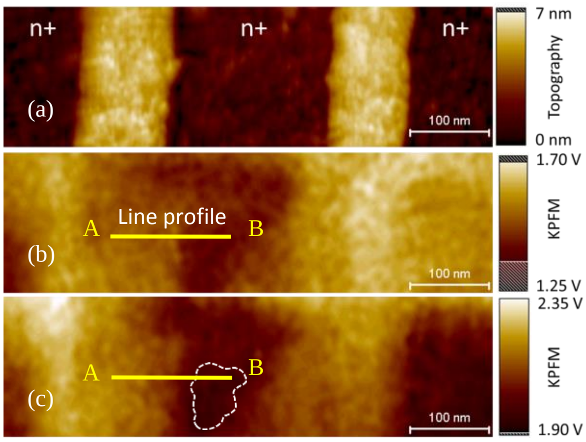

Fig.2 (a) Topography image; (b-c) KPFM images of selectively-doped channel, V_{sub}, 0V and -4V respectively. Imprint of the doping mask appears on topography image. Darker and brighter regions correspond to doped and non-doped areas, respectively. Dopant cluster surrounded by uniformly distributed donors is outlined in (c).