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KFM Measurement of Nano-Scale Selectively Doped Silicon Channel

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Introduction

Continuous miniaturization of electronic devices led us to the point where proper arrangement of individual dopants starts to play a key role. Devices with single dopants working as a quantum dots (QDs) where single-electron tunneling occurs have been already reported[1-3]. However, precise control of dopant position is still challenging. Doping through nano-patterned masks should result in obtaining localized dopant-QDs in the channel. We present Kelvin probe force microscope (KFM)[4] observation of the transistor with channel selectively doped with phosphorous by conventional thermal diffusion.

Selectively-doped SOI-FET fabrication

Devices studied are SOI-FETs with ultra-thin top oxide layer and substrate Si working as back gate. These features are required for KFM measurement. The channel dimensions are 20×1000×500 nm. Device was doped with phosphorous ($N_D \approx 5 \times 10^{18}$ cm^{-3}) by thermal diffusion. Doping was done through the multiple parallel nano-slits opened in oxide mask using an e-beam lithography technique [Fig. 1(a,b)]. Device under investigation has 17 slits, 25 nm wide doped slits with 100 nm inter-slit spacing.

Results of KFM measurements

Figure 2(a) shows 350 nm × 50nm area scan of topography image of 2 doped slits. Slits resulted from subsequent fabrication steps can be clearly seen by AFM.

Figure 2(b) shows electronic potential image corresponding to measured topography shown in Fig. 2(a). Measurement was done under V_{BG} = 0 V (back gate bias), for a temperature of 300 K and in high vacuum (1.3×10^{-5} Pa).

Under the above conditions, dopants should be ionized, but fully screened by the electrons, since there is no depletion of the channel. Nevertheless, due to doping, the band structure and Fermi level are modulated. By selective doping, we obtained periodical band structure with different Fermi levels, corresponding to doped and undoped regions along the channel. This structure can be directly mapped by KFM measurement as can be seen in Fig. 2(b), where lower electronic potential refers to heavily-doped regions. By comparing topography and KFM image, we can see that the size of doped areas is in a good agreement with designed slit size.

Conclusions

Selectively-doped SOI-FETs were fabricated and characterized by KFM. Successful formation of doped slits by thermal diffusion was proved by KFM measurement and electronic potential profile analysis.

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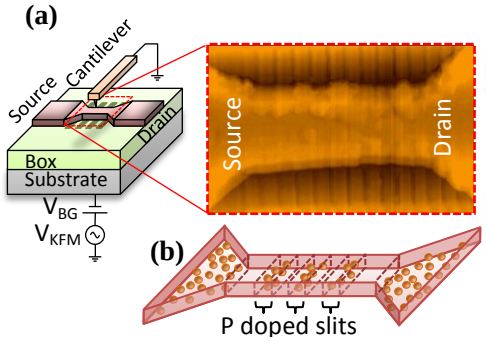

Fig. 1 (a) KFM measurement setup. Topography of the channel. (b) Structure of device.

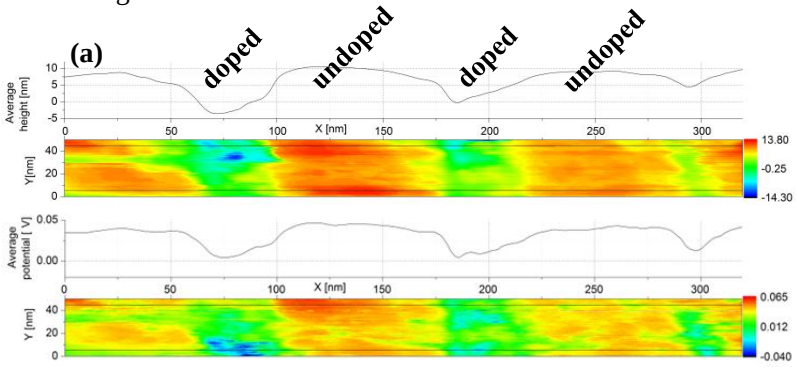

Fig. 2 (a) AFM image with average profile. (b) KFM electronic potential with average profile across the channel.

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