Electrostatic Doping in Carbon-based Nanoelectronics Devices

Joachim Knoch

Institute of Semiconductor Electronics
RWTH Aachen University
Sommerfeldstraße 24
52074 Aachen, Germany
carbon-based materials hold promise to realize ultimate FETs due to optimum scalability and electronic transport properties
Introduction – Issues with Doping

- need excellent gate control of channel and screening of gate impact on source contact
- low density of states such as in carbon nanotubes (1D) or graphene detrimental for screening

electrostatic doping

Tunable Polarity in CNFETs

- $L_{bg} \approx 200\text{nm}$
- $L_{ch} \approx 200\text{nm}$
- $d_{ox-SiO_2} = 10\text{nm}$
- $d_{ox-Al} = 4\text{nm}$

- ambipolar behavior if both gates biased in the same direction
- electron and hole injection through Schottky-barrier at Ti-nanotube interface

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- **unipolar device behavior if both gates are biased with opposite polarity**
- **n- and p-type CNFETs possible due to excellent gate control**

Conventional CNFETs

- device should be scalable to $L < 20\text{nm}$ without SCE
- increasing off-state leakage for short conventional CNFETs

Tunnel-FET based on CNTs

\[ d_{NT} \approx 1.4\text{nm} \quad d_{ox} = 4\text{nm} \]

\[ S = 40\text{mV/dec} \]

Electrostatic Doping in Graphene

L=1mm  
W=1mm  
$\text{t}_{\text{ox,\text{bg}}}=300\text{nm}$  
$\text{t}_{\text{ox,fg}}=10\text{nm}$  
Pd contacts

- back-gate characteristics of device „B“ show double peak-structure
- second peak much less pronounced than main peak

Electrostatic Doping in Graphene


- second peak observable
Electrostatic Doping in Graphene

- back-gate voltage characteristics for different coupling strengths
- second peak unobservable if coupling too large

Electrostatic Doping in CNT Tunnel-FETs

- significantly improved on-state due to improved screening
- steep inverse subthreshold slope of 23mV/dec over several orders of magnitude

T. Grap and J. Knoch, submitted for publication
Electrostatic Doping

Electrostatic Doping

A
side-gate  center gate  side-gate

B
SOI  LOCOS-oxide  BOX

\(d_{\text{Al}_2\text{O}_3}\)
\(d_{\text{SiO}_2}\)

doped Si
Al

\(V_{ds} = 0.15V\)
\(S = 720mV/dec\)

\(V_{g,\text{side}} = 5V, 4V(\text{source}), -13V(\text{drain})\)

\(V_{g,\text{side}} = 15V, 10V, 8V, 6V, 4V, 3V, 1V, 1.5V\)

\(V_{gs} (V)\)

\(I_d (A)\)

source  center-gate  side-gate  drain

nanowire

BOX
Conclusion

- low density of states detrimental for novel transistor concepts such as tunnel FETs due to insufficient screening

- electrostatic doping avoids issues related to doping and adds flexibility for general investigations of carbon based nanostructures
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