IWN 2014 WROCŁAW

Simulations of the effect of interface traps distribution on the electrical parameters of normally-off AlGaN/GaN MOS-HEMTs

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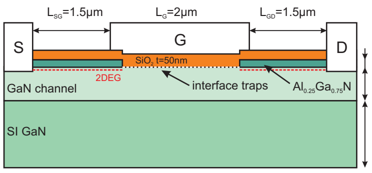
The International Workshop on Nitride Semiconductors (IWN2014), 24-29 August, Wrocław, Poland

Introduction

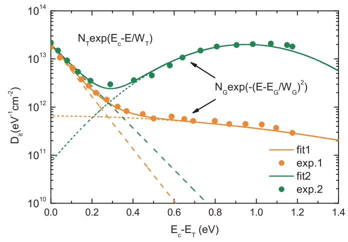
High Electron Mobility Transistors based on the AlGaN/GaN heterostructures can be used for power electronics owing to the excellent electro-physical properties of III-N materials, such as high critical electric field and high carrier concentration and mobility of two-dimensional electron gas (2DEG) in the channel. One of the essential requirements is enhancement mode (normally-off) operation. Several different layouts have been developed to fulfil the principal assumption and one of the most promising are the recessed gate design or a hybrid MOS-HEMT structure. However, the major drawback of the latter structure is poor quality of GaN/dielectric interface which may cause low mobility and high on-resistance of final devices. The aim of this work is to investigate how various interface traps distribution profiles affect electrical characteristics and parameters of normally-off AlGaN/GaN HEMTs.

Simulation details



- **HEMT structure**:
  buffer layer - GaN:C 2.5μm
  channel - UID GaN - 500nm
  $Al_{0.25}Ga_{0.75}N$ - 25nm
- **gate dielectric** - SiO_2 (t=50nm, ε$_r$=3.9)
- **channel mobility**: Lombardi model - $\mu^{-1}=\mu_{bulk}^{-1}+\mu_{sr}^{-1}+\mu_{ac}^{-1}$
- **2DEG mobility** - 1500 cm²/Vs,
- **ohmic contact resistance** - 0.6Ωmm

simulator: Silvaco ATLAS

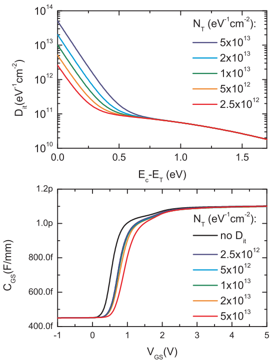


- The energetic distribution of interface states (Dit) was parameterized by using sum of Gaussian like profile for states located in the depth of energy gap and exponential like profile near band edges:

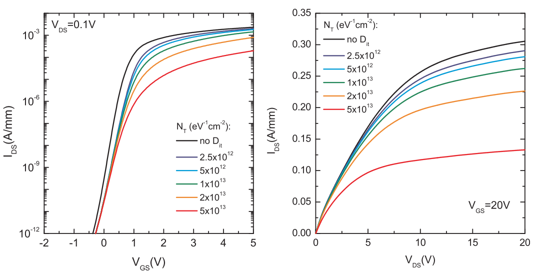
$$D_{it}=N_T\exp(E_c-E/W_T)+N_G\exp(-(E-E_G/W_G)^2)$$

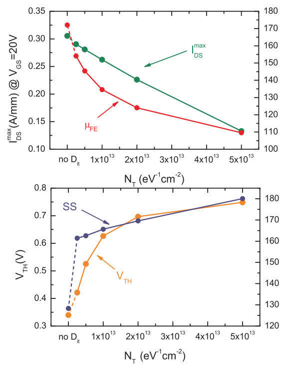
- reference experimental data: Y.Hori, C.Mizue, T.Hashizume, *Jpn. J. Appl. Phys.* 49, 080201 (2010)
- calculation of relevant transistor parameters: subthreshold swing(SS), threshold voltage(V_{TH}), field effect mobility (μ_{FE})

Impact of traps density near band edge



- **D_{it} profiles param.**: W_T=0.08 eV, N_G=1x10^{11} eV^{-1}cm^{-2}, E_G=0 eV, W_G=1.3 eV
- N_T= 5x10^{13}, 2x10^{13}, 1x10^{13}, 5x10^{12}, 2.5x10^{12} eV^{-1}cm^{-2}



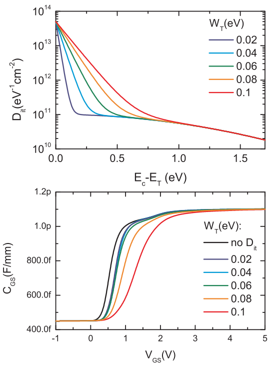


- The value of density of interface state at band edges have mainly impact on field-effect mobility:

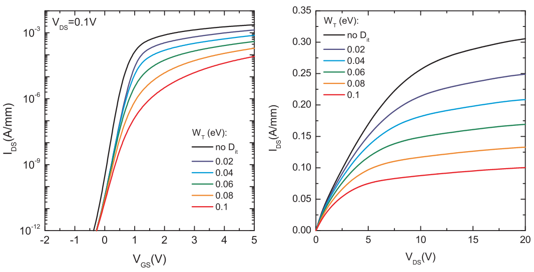
  decreasing of μ_{FE} from 170 to 110 cm²/Vs

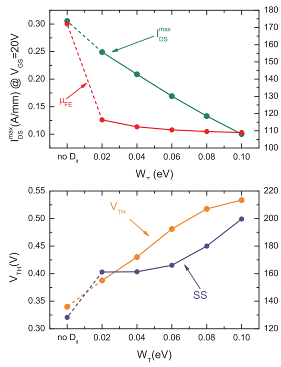
- C_{GS}-V_{GS} curve and threshold voltage shifted towards positive V_{GS} values of about 0.4V for N_T=5x10^{13} eV^{-1}cm^{-2}
- SS increased from 130 to 180 mV/dec

Impact of the slope of D_{it} energetic profiles near band edge



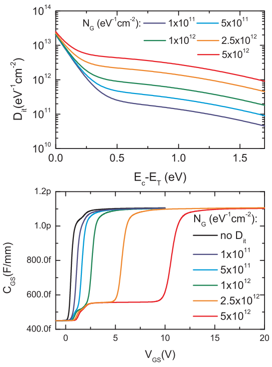
- **D_{it} profiles param.**: N_T=2x10^{13} eV^{-1}cm^{-2}, N_G=1x10^{11} eV^{-1}cm^{-2}, E_G=0 eV, W_G=1.3 eV
- W_T= 0.02, 0.04, 0.06, 0.08, 0.1 eV



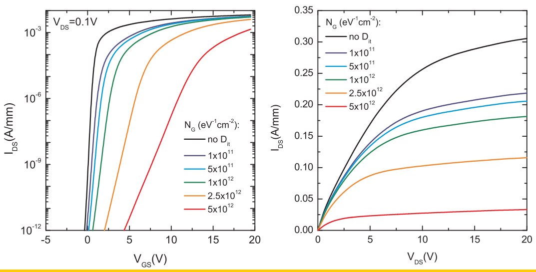


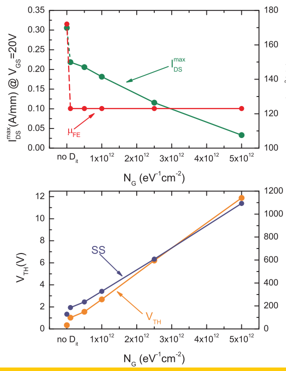
- The slope of the D_{it} profiles causes increase of SS from ideal SS=130 to 200 mV/dec and only a slight decrease μ_{FE} for assumed values of W_T (and other parameters constant).
- C_{GS}-V_{GS} curves shows a significant stretching-out with increasing W_T
- V_{TH} increased only obout 0.2V

Impact of traps density located deep in the band gap



- **D_{it} profiles param.**: N_T=2x10^{13} eV^{-1}cm^{-2}, W_T=0.08 eV, E_G=0 eV, W_G=1.3 eV
- N_G=1x10^{11}, 5x10^{11}, 1x10^{12}, 2.5x10^{12}, 5x10^{12} eV^{-1}cm^{-2}





- In the case of trap states located far from the band edge, their density influenced very strongly on the threshold voltage and subthreshold swing:
- For highest N_G value 5x10^{12} eV^{-1}cm^{-2} V_{TH} increased to about 12V and SS increased to 1V/dec.
- C_{GS}-V_{GS} curves shows a significant shift towards positive values.
- Field effect mobility was not affected by deep interface states.

Conclusions

- the greatest impact on the μ_{FE} has the density of traps located at band edges
- different values of Dit located deep within the band gap did not affect μ_{FE}
- the greatest impact on the V_{TH} and SS has the density of traps located deep in the band gap
- slope of D_{it} profiles near band edges causes significant streching-out of C_{GS}-V_{GS} curve

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The research was partially supported by the Foundation for Polish Science Ventures Programme co-financed by the EU European Regional Development Fund. Andrzej Taube was also supported by the European Union in the framework of the European Social Fund through the Warsaw University of Technology Development Programme.

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FNP Foundation for Polish Science

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

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