Ferroelectric thin film field-effect transistors based on ZnO/$BaTiO_3$ heterostructures

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Polarization coupling in $BaTiO_3$ – ZnO structures

Ferroelectric $BaTiO_3$ (BTO)

- Perovskite structure (tetragonal at RT, a_0=3.994 Å c_0= 4.038 Å)
- Remanent, switchable, spontaneous Polarization P_{SP}

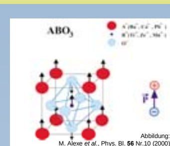


Abbildung: M. Alexe et al., Phys. Bl. 56 Nr.10 (2000)

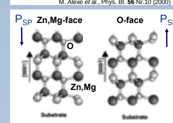


Figure: O. Ambacher et al., JAP 87, 334 (2000)

Piezoelectric ZnO

- Wurtzite structure (a_0=3.250 Å; c_0=5.21 Å)
- Nonswitchable, spontaneous Polarization P_{SP}

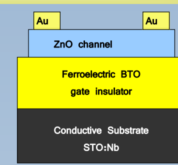
Polarization Coupling

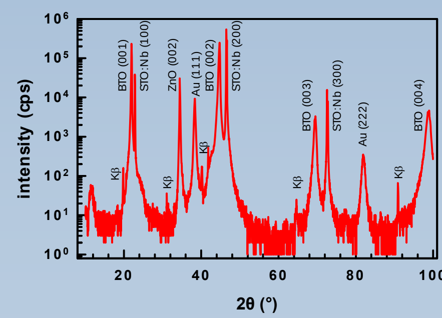
- Pinning of ferroelectric polarization by sponatenous ZnO polarization
- Bistable switching behaviour, parallel and antiparallel orientation
- Carrier concentration in the ZnO controlled by polarization in the BTO
- Depletion layer formation as described in [1]
- Effect makes device suitable for fabrication of ferroelectric thin film transistors

→ Transparent, non-volatile memory element

Samples

- BTO grown by PLD on lattice matched $SrTiO_3$ (STO) substrate
- Back contact established by Nb doping of the substrate
- BTO layers of 800 nm thickness, ZnO channels of 50 nm
- Ohmic front contacts on ZnO by DC sputtered Au
- Described in detail in [2]





- XRD shows epitaxial growth of BTO and ZnO
- BTO and STO:Nb show perfect in-plane alignment
- ZnO shows 30° in-plane rotational domains (not shown here)

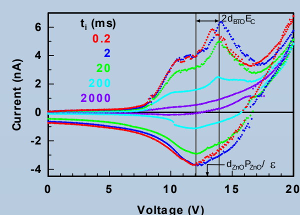
Electric properties of single ferroelectric layers and BTO-ZnO heterojunctions

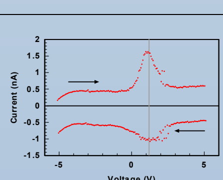
Observation of ferroelectric switching currents by I-V measurements

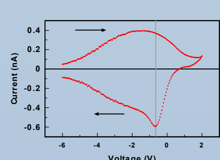
- Heterostructures with 500 nm ZnO thickness allowed observation of ferroelectric switching currents

→ Spontaneous polarization of ZnO in this sample estimated to be P_{SP}=0.2±0.05 µC/cm²

→ Coercive field of BTO in this sample estimated to be E_C= 12.5±1 kV/cm

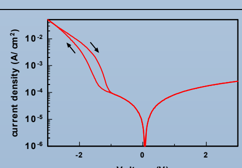






- Very low leakage currents, as necessary for FET structures
- Spontaneous polarization of ZnO in two FET structures on the same sample estimated to P_{SP} = 0.12 µC/cm² and P_{SP} = −0.08 µC/cm²

→ Probably both polarities present in one sample, possible origin: opposite polarities in 30° rotational domains

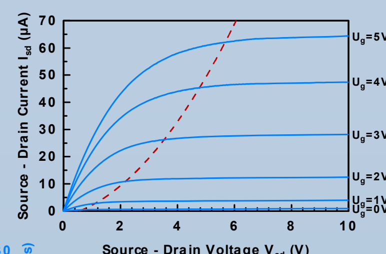


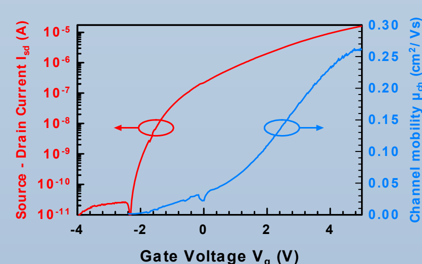
- Resistance switching observed in heterostructures with low resistance BTO
- Change in resistance due to polarization controlled depletion layer in ZnO, as predicted in [1]

→ Suitable for ferroelectric FET

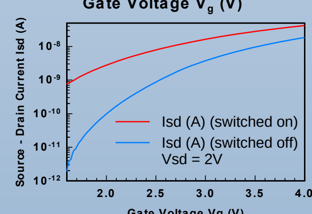
Measurement of field effect

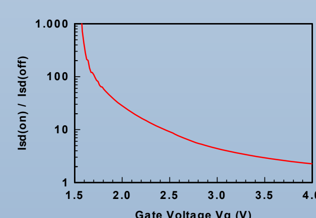
- Pronounced field effect observed with high source – drain currents in sample E1852
- Pinch off follows theoretically predicted behaviour
- Quasi static capacitance measurements of BTO gate give dielectric constant of ε = 263 at 300K (Literature value e.g. 280 [3])





- source – drain current can be controlled by gate voltage over 6 orders of magnitude
- Relatively low channel mobilities of up to 0.27cm²/Vs, most probably due to surface scattering[3] and grain boundaries
- Transfer characteristic could be reversibly switched by large gate voltages permanently
- Ratio between switched on and switched off state could be as large as 1000, depending on the read-out gate voltage





Conclusions

- Growth of ZnO thin film field effect transistors with ferroelectric BTO gate on lattice matched STO substrates by pulsed laser deposition
- Switching currents of BTO observed in I-U measurements, coupling with the ZnO polarization influences the switching behaviour as described in [1]
- Estimation of material constants possible
- Spontaneous polarization of ZnO between P_{SP} = −0.08 µC/cm² and P_{SP} = 0.2 µC/cm² indicating different polarities of ZnO (literature values P_{SP}=7±2 µC/cm²) [5-7] Pronounced field effect observed, V_g controls I_{sd} by 6 orders of magnitude
- Permanent switching of the transfer characteristic upon large V_g values

→ Device suitable as a transparent non-volatile memory element

References

[1] V. Voora, T. Hofmann, M. Brandt, M. Lorenz, M. Grundmann, N. Ashkenov, and M. Schubert, J. of Electronic Materials **37**, 1029 (2008)

[2] M. Lorenz, M. Brandt, J. Schubert, H. Hochmuth, H. v. Wenckstern, M. Schubert, and M. Grundmann, Proc. SPIE Vol. 6474, 64741S (2007)

[3] N. Hiroshiba, R. Kumashiro, K. Tanigaki, T. Takenobu, Y. Iwasa, K. Kotani, I. Kawayama and M. Tonouchi, Appl. Phys. Lett. **89**, 152110 (2006)

[4] B. V. Zeghbroeck, Principles of Semiconductor Devices, e-book (2004) http://ece.colorado.edu/~bart/book/book/index.html

[5] Y. Kim, K. Page, and R. Seshadri Appl. Phys. Lett. **90**, 101904 (2007)

[6] J. Jerphagnon and H. W. Newkirk Appl. Phys. Lett. **18** (6), 245 (1971)

[7] F. Bernardini, V. Fiorentini, and D. Vanderbilt Phys. Rev. B **56**, R10024 (1997)

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