



Influence of Si substrate preparation on polarity of GaN nanowires grown on Si(111) by PAMBE: Kelvin Probe Force Microscopy studies



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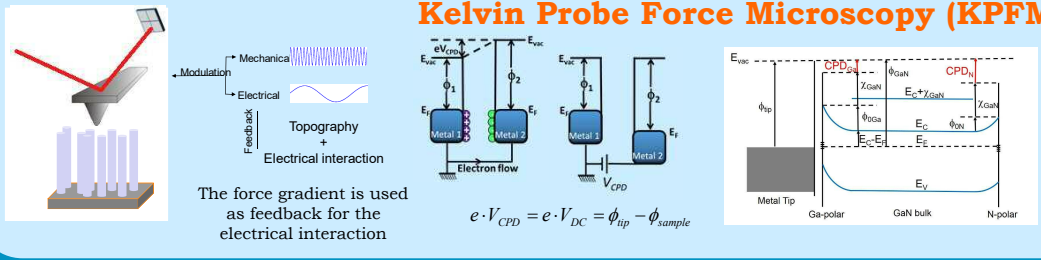
Introduction

- GaN nanowires (NWs) grown by plasma-assisted MBE on Si(111)
- self-induced nucleation; no catalyst used
- Kelvin Probe Force Microscopy (KPFM) used to assess polarity of NWs
- topography and contact potential difference (CPD) maps analyzed [A. Minj et al. *Nano Lett.* **15** (2015) 6770].
- the aim:** to correlate uniformity of NWs' polarity in the ensemble with the recipe of Si substrate preparation

Growth procedure

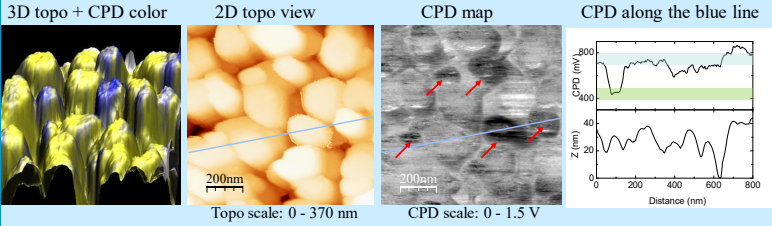
- Si substrates prepared according to **Procedures A – E** as described below
 - Si substrates exposed to nitrogen flux @ ~750°C for ~15 min to create silicon nitride layer on their surfaces * (not applied for substrates with amorphous Al_xO_y buffer layer deposited by ALD)
 - GaN NWs grown by PAMBE @ ~750°C under N-rich conditions
- *Wierzbička et al. *Nanotechnology* **24** (2013) 035703

Kelvin Probe Force Microscopy (KPFM)



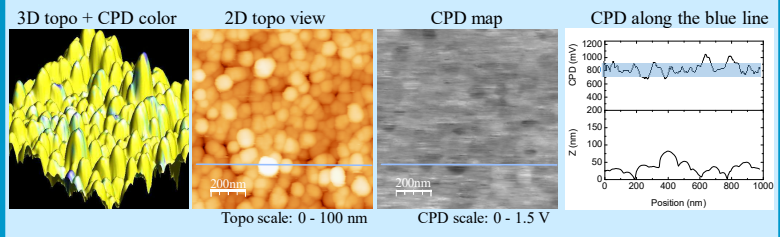
- allows measuring the polarity of individual NWs over an area of tens of μm^2 and provides statistics on the polarity of the ensemble
- Nondestructive
- Expected N-polar Ga-polar CPD difference: 550mV

Procedure A: HF dip followed by thermal removal of hydrogen passivation @ ~750°C in the growth chamber



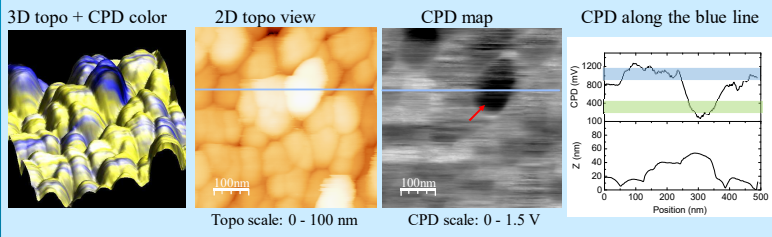
Result: as high as 20% of NWs with reversed polarity (i.e. Ga-polar) found (marked by red arrows); HF dip leads to clean 7x7 substrate surface reconstruction but some islands of residual oxide are apparently left that induce growth of Ga-polar GaN NWs [Borysiuk et al. *Nanotechnology* **25** (2014) 135610].

Procedure D: epi-ready Si(111) substrates; native oxide desorbed thermally @ ~1000°C in the growth chamber



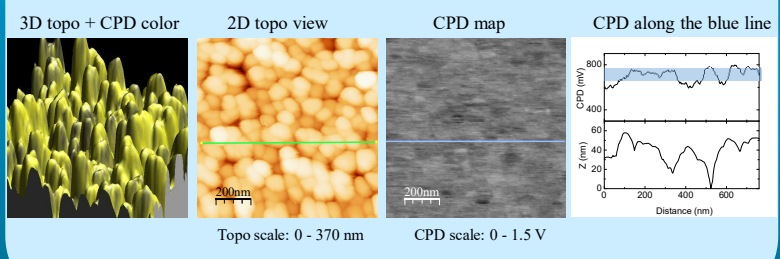
Result: uniform N-polarity; 120 NWs analyzed; additional step of substrate cleaning in the Ga flux after oxide desorption (tested for another sample) does not change the result

Procedure B: RCA wet etching; oxide desorbed thermally @ ~1000°C in the growth chamber



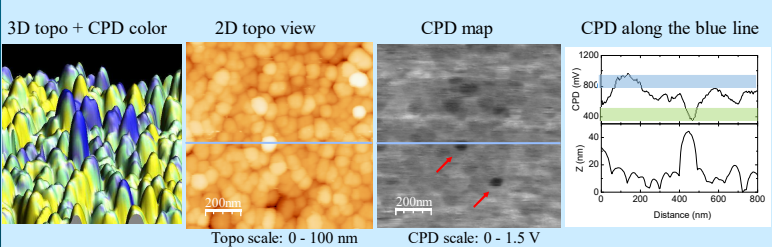
Result: 4% of NWs with reversed polarity (marked by red arrow); 50 NWs analyzed; some improvement caused by HT oxide desorption under UHV; RCA wet etching possible source of residual contaminants?

Procedure E: Si(111) substrate with 15 nm thick amorphous Al_xO_y buffer deposited at low T by atomic layer deposition [Sobanska et al. *J. Appl. Phys.* **115** (2014) 043517; Sobanska et al. *Nanotechnology* **27** (2016) 325601]. No intentional nitridation before GaN growth.



Result: uniform (99.8%) N-polarity; more than 400 NWs analyzed

Procedure C: RCA wet etching; oxide desorbed thermally @ ~1000°C in the growth chamber + cleaning in the Ga flux (deposition of a few MLs of Ga @ LT followed by Ga desorption @ HT)



Result: 3% of NWs with reversed polarity (marked by red arrows); 180 NWs analyzed; substrate cleaning in the Ga flux does not remove residual contaminants in this case

Summary

- KPFM is an efficient tool for polarity assessment of individual GaN NWs in large area NW ensembles
- residual oxide islands may lead to polarity inversion of GaN NWs in agreement with our previous study [Borysiuk et al. *Nanotechnology* **25** (2014) 135610].
- uniformity of NWs' polarity in the ensemble strongly depends on the recipe of Si substrate preparation prior to the growth of GaN:
 - HF dip procedure alone leads to heavily mixed polarity of GaN NWs
 - thermal oxide desorption under UHV from epi-ready Si substrates required for uniform ensemble of N-polar GaN NWs
 - no mixed polarity observed in GaN NWs grown on amorphous Al_xO_y buffer