ZnO nanorod electronic devices

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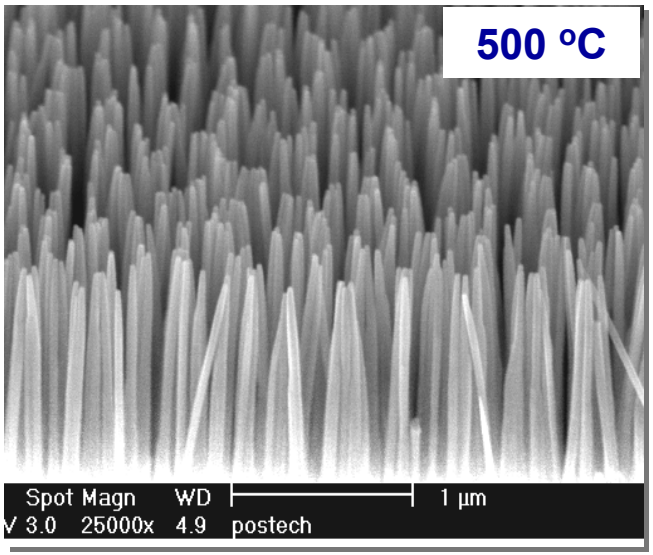
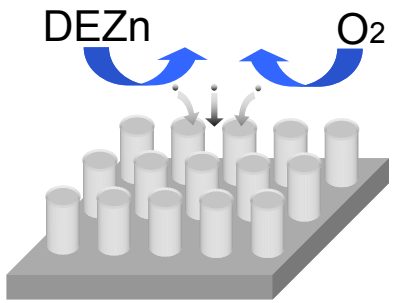
- Well-developed semiconductor technology: MOCVD
- High purity
- Nanodevices



- Many different substrates:
  Sapphire, Si, quartz and glass
- MOCVD: easy scale-up

Catalyst-free MOCVD

Appl. Phys. Lett. 80, 4232 ('02)



- No use of metal catalysts even without any special substrate treatment
- Extreme case of island growth: at the initial stage of growth, c-axis oriented ZnO nano-crystallites are formed by random nucleation process, then the nano-crystals are elongated due to a higher growth rate along the ZnO c-axis direction, forming vertically aligned ZnO nanorods.

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High purity ZnO nanorods

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- High purity
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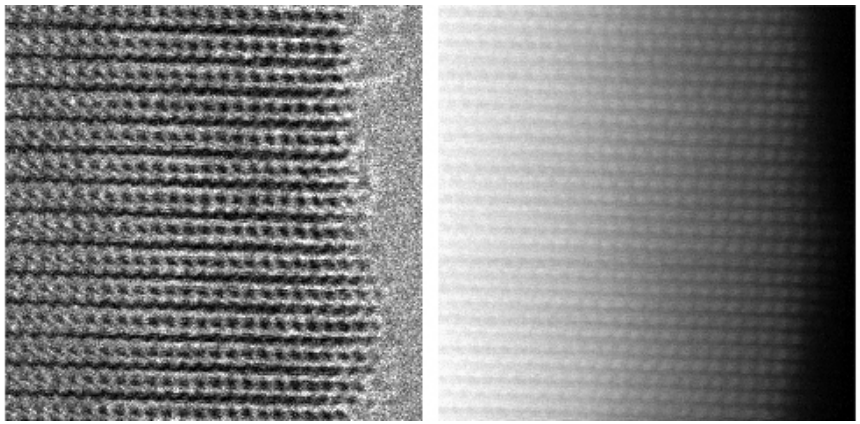
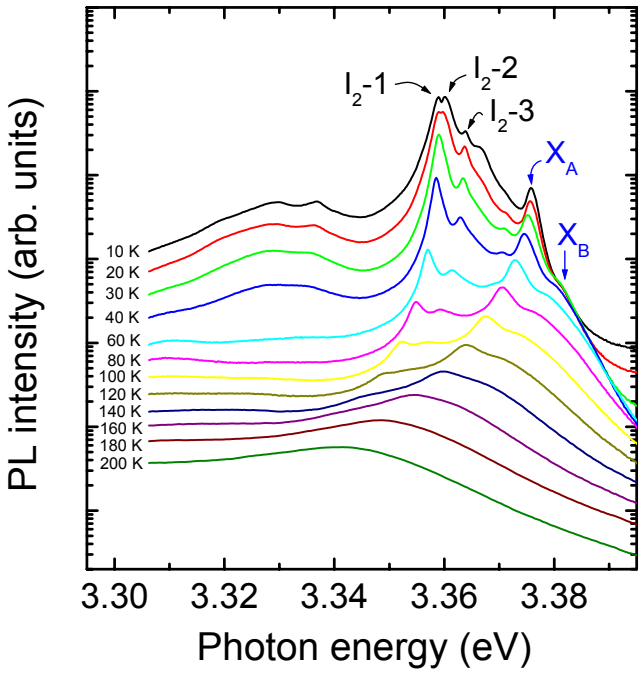
TEM images



Almost defect-free single crystallinity in TEM images

- Temperature-dependent PL spectra



- Low temperature PL spectroscopy: sensitive to small amount of impurities
- Peak separation with small FWHM in the range of 1-3 meV: high optical quality
- Free exciton peak at 3.376 eV
- Free exciton observation at 10 K: high purity

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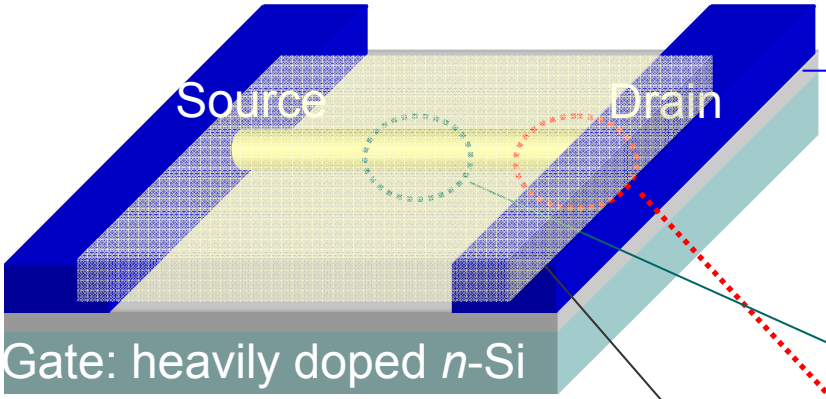
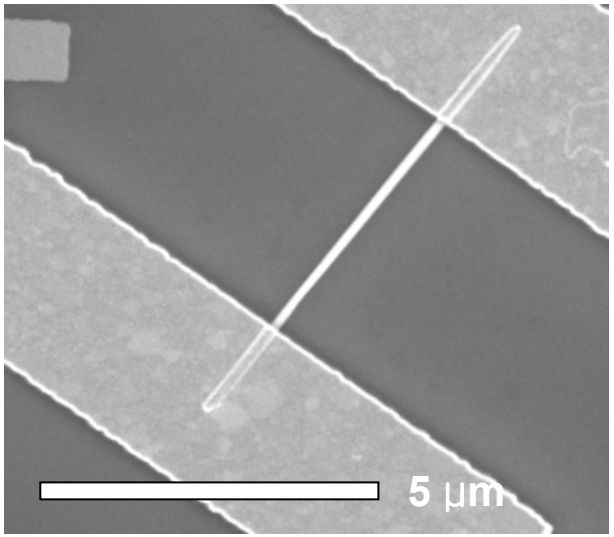
Fabrication of ZnO nanorod MOSFETs

- Well-developed semiconductor technology
- Nanodevices





-A 250-nm-thick silicon oxide layer as an insulating gate oxide layer on a heavily doped *n*-type silicon substrate.

-Single crystal ZnO nanorod

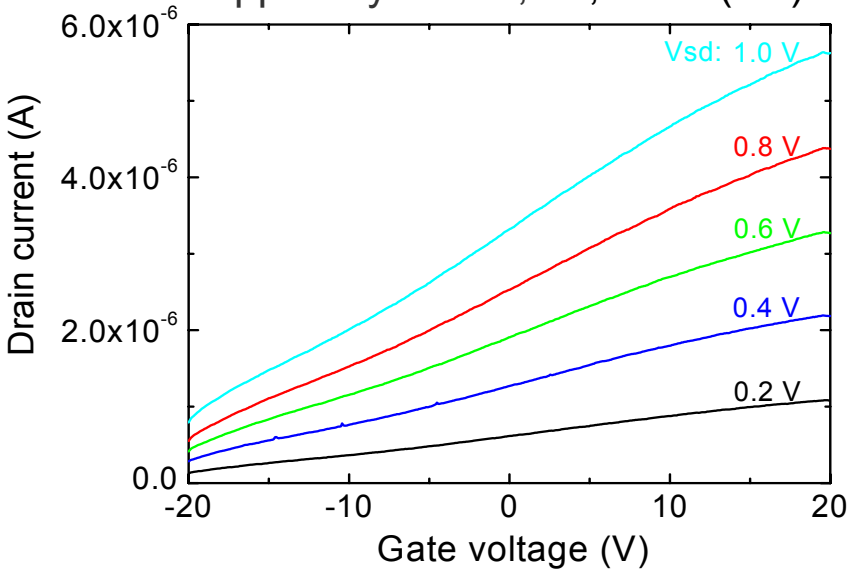
-Metal contact pattern: e-beam lithography and metal evaporation & lift-off

-Au/Ti electrodes (good ohmic)

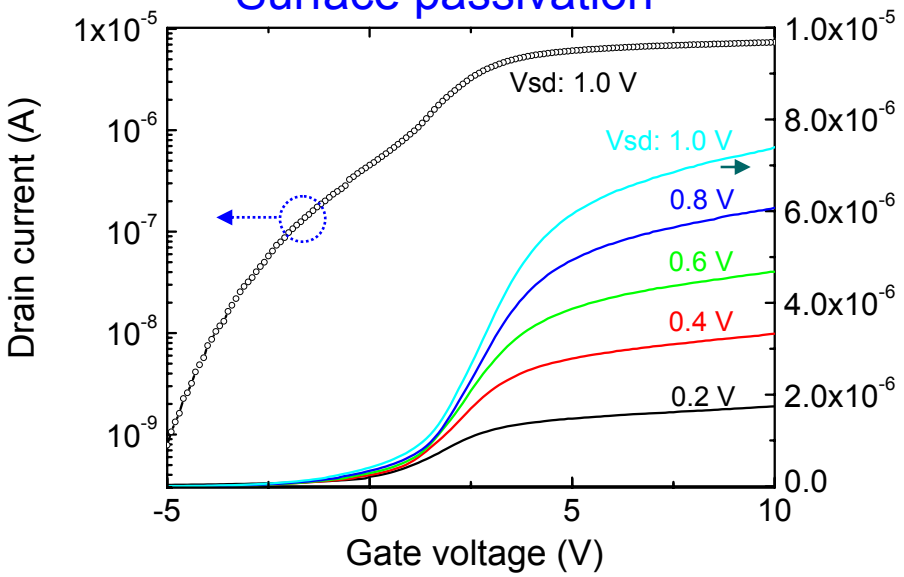
Polymer coating: surface passivation for reducing surface effect and enhancing gate effect

Electrical characteristics of surface-passivated FETs

Appl. Phys. Lett., **85**, 5052 ('04).



Surface passivation



- The electrical characteristics of ZnO nanorod FETs were significantly improved by coating polyimide on ZnO nanorod surfaces.

	Before	After
Turn on voltage	> –20 V	~ –5 V
Transconductance (g_m/W)	1-2 μS/μm	20 μS/μm
Current ON/OFF ratio	~7	10^4-10^5
Subthreshold swing (S)	–	1.4 V/decade

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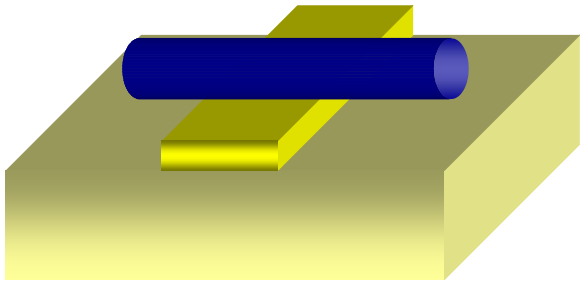
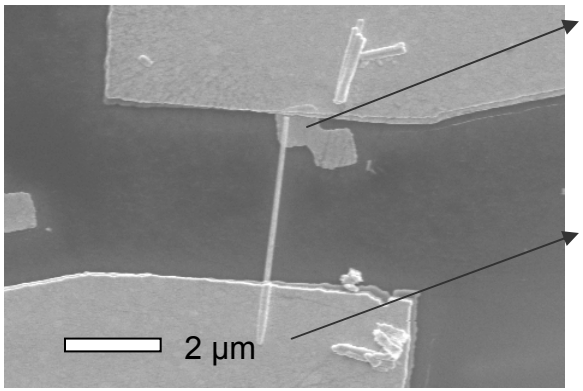
Schottky diodes, MESFETs



Schottky gate

- Schottky contact: gate electrode
  - no insulating layer between a Schottky gate and a channel
  - large capacitive coupling
  - high signal power gain
  - fast switching useful for high frequency device and circuit applications
  - local gate: individual control of transistor for integration



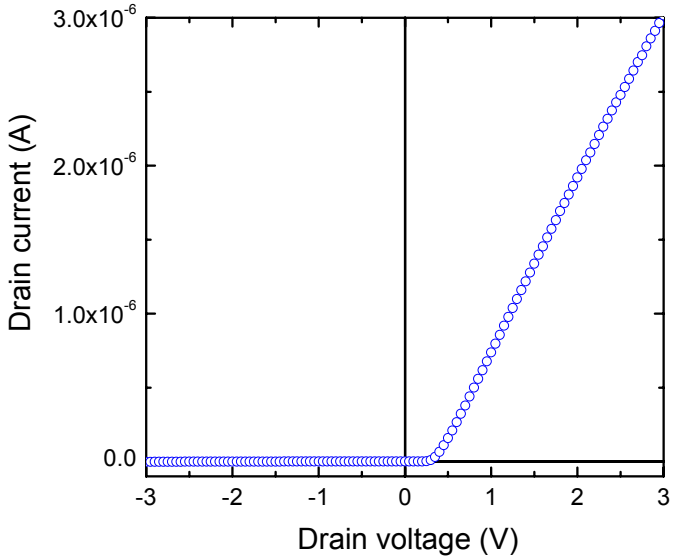
Au:Schottky contact

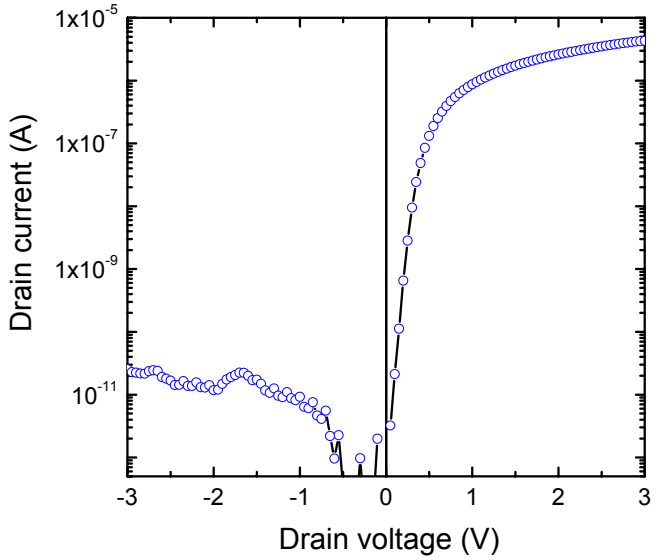
Ti/Au:ohmic contact

ZnO nanorod Schottky diode

- Metal oxide semiconductors:
  - air stable surface without formation of an insulating native oxide layers
  - clean and abrupt M/SC interface without any specific etching process

Current-voltage characteristics of ZnO nanorod Schottky diodes





- Excellent rectifying current-voltage characteristic
- Forward-to-reverse bias current ratio (I_f/I_r): ~10^5–10^6
- Ideality factor (η): ~1.2: well-defined interface between a ZnO nanorod and a Au layer

$$I = I_s \exp\left(\frac{qV}{\eta K_b T} - 1\right)$$

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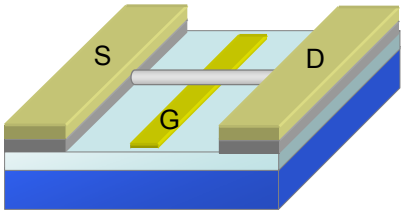
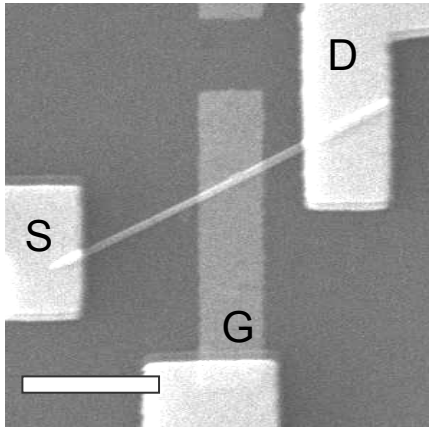
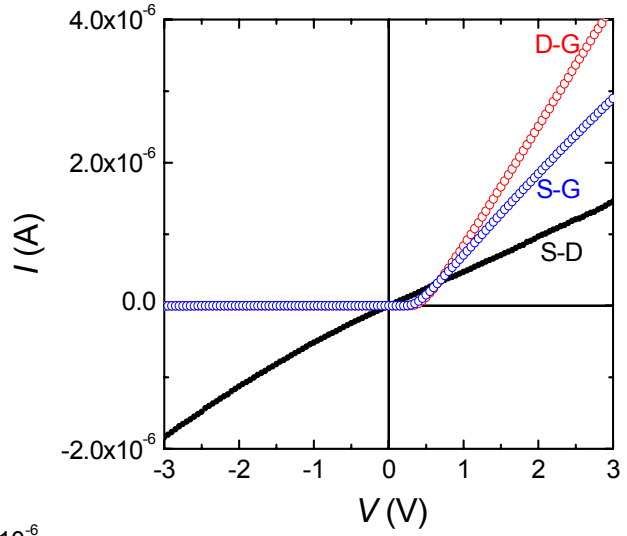
Electrical characteristics of ZnO nanorod MESFETs



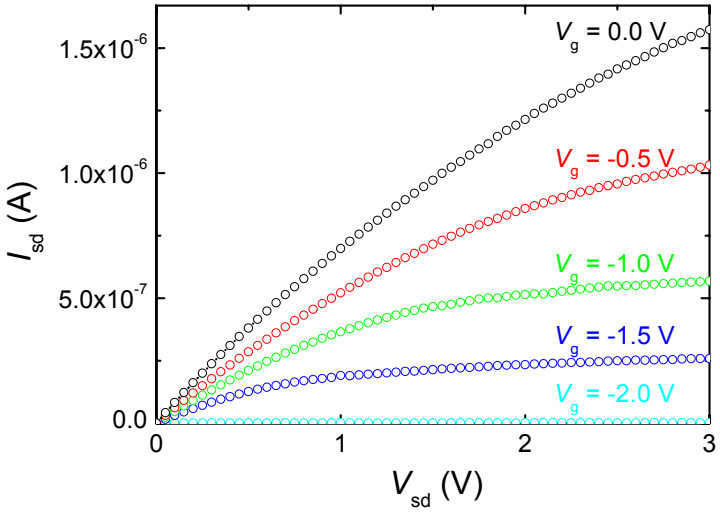
S, D: Au/Ti ohmic contact

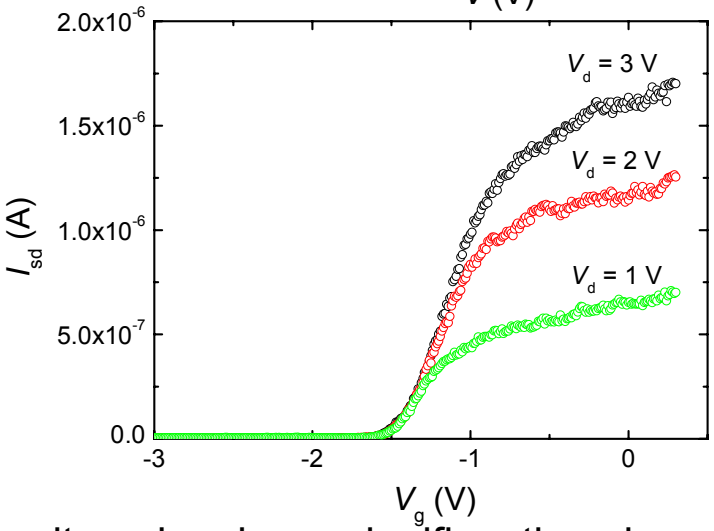
G: Au Schottky contact





ZnO nanorod MESFETs





-Conductance response to the gate bias voltage has been significantly enhanced: low turn-on voltage of – 1.5 V.

- Individual MESFET operation for logic gate operation

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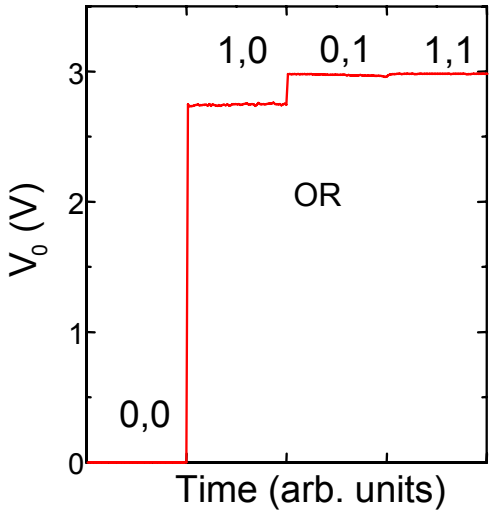

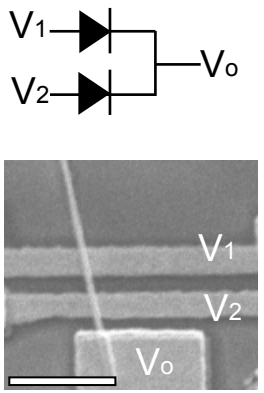

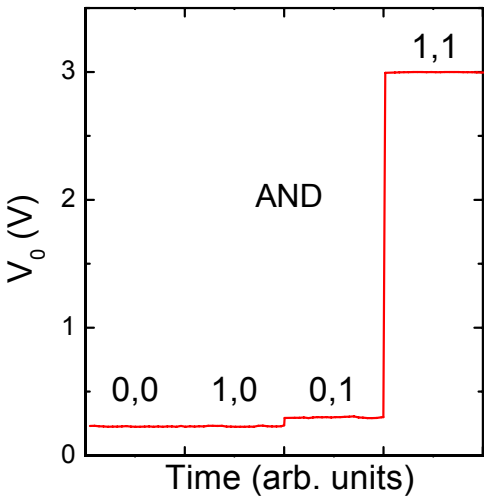

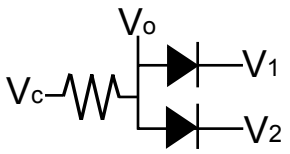

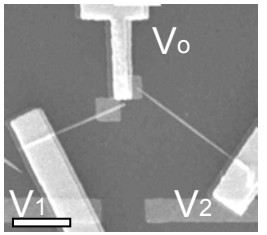

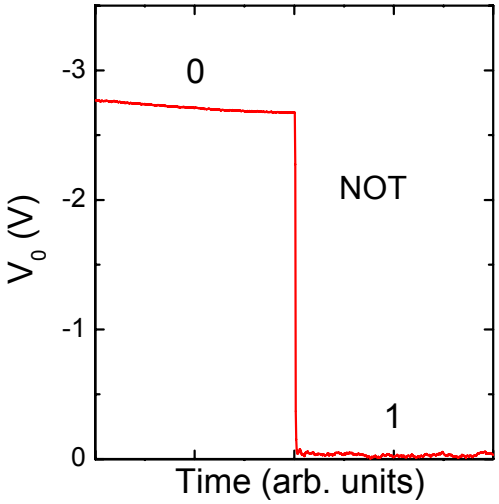

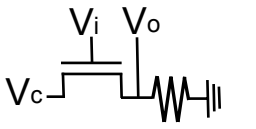

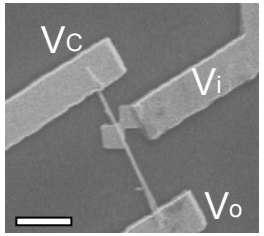

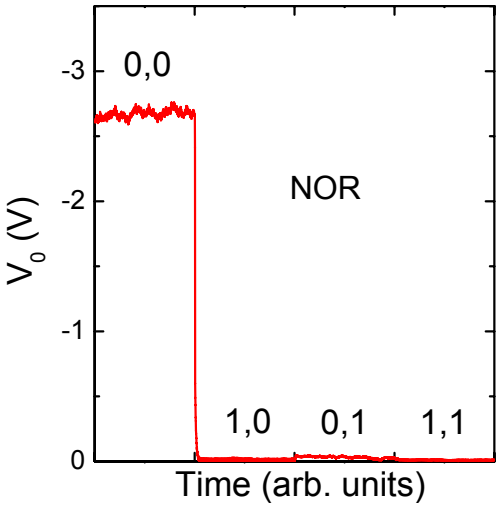

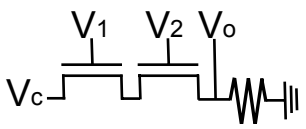

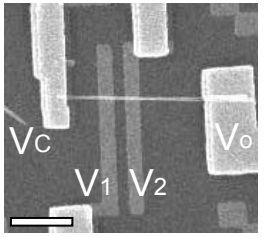

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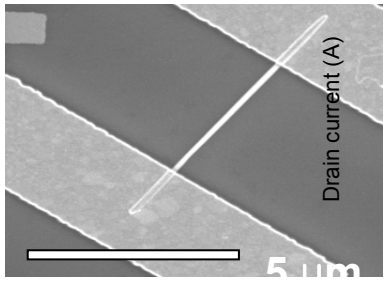
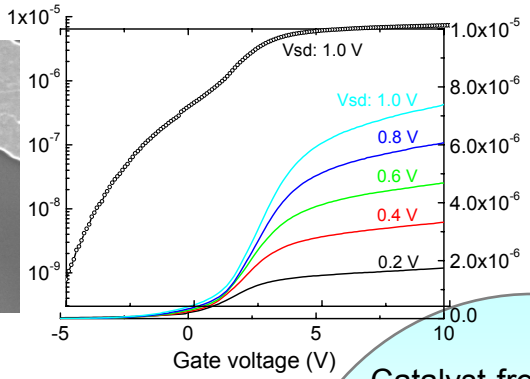
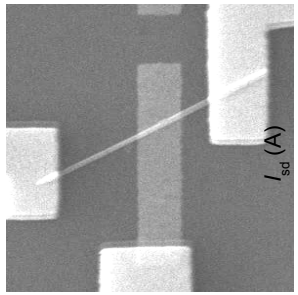
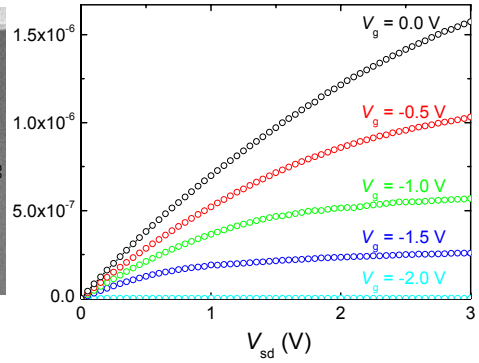
High quality ZnO nanorods grown by catalyst-free MOCVD can be applied for electronic nanodevices including field effect transistors, Schottky diodes, and logic gates.

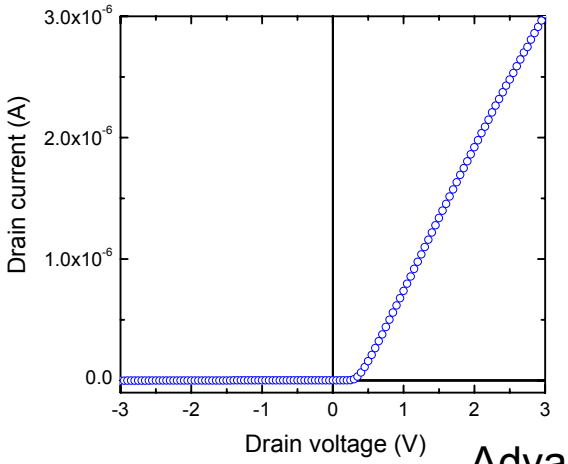


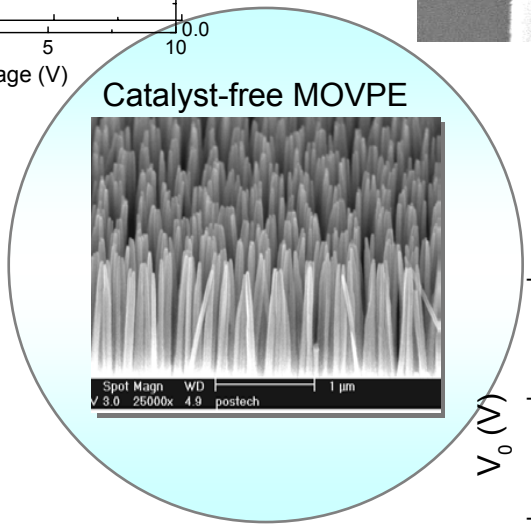


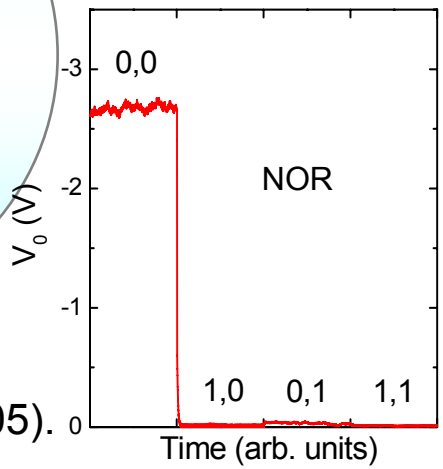


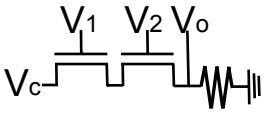


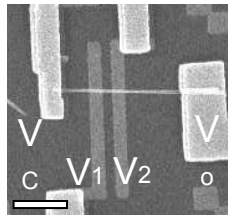
Appl. Phys. Lett., **85**, 5052 ('04).











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Research activities

Nanomaterials

- Catalyst-free MOCVD of ZnO nanorods
- ZnO/ZnMgO nanorod quantum structures with composition modulation along either radial or axial direction.
- Catalyst-free and catalyst-assisted growth of GaN nanorods
- Chemical solution method to grow nanoparticles, nanorods, and nanodisks
- Structural, optical, and electrical characterizations of nanomaterials

Nanorod device applications

- Metallization on semiconductor nanorods (either ohmic or Schottky contact)
- ZnO nanorod photonic devices (light emitting devices)
- ZnO nanorod electronic devices (FETs, Schottky diodes, and logic gates)