Rectifying Schottky Nanocontacts on Gold Nitride and Indium Nitride Nanodomains

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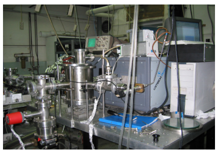
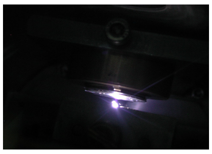
Abstract

Metal-semiconductor contacts, also known as Schottky contacts, are very important in the functionality of modern electronic devices. Recent progress in the production of high quality materials in the nanoscale has allowed for the development of miniature junctions, further reducing the size and increasing the efficiency of devices such as transistors or memory chips. In this work, gold nitride and indium nitride nanodomains are grown by pulsed laser deposition with a molecular fluorine laser at 157 *nm* in nitrogen environment and at ambient temperature and pressure. Schottky nanocontacts with a high work function metal are then formed, using the Pt/Ir tip of a conductive atomic force microscope as the one electrode and a low work function metal as the other. Conductivity measurements show that both nitrides exhibit semiconductive behaviour. The rectifying I-V characteristics indicate that thermionic emission through the Schottky barrier is the predominant electron emission process. Taking into consideration the work functions of the two metal electrodes, lower and upper limits of the electron affinity of both nitrides can be derived. Surprisingly, the estimated ideality factor of both nanocontacts is much higher than unity, in contrast with the experimental current rectification. A possible reason is that the band bending at the metal-semiconductor interface results in a lower potential difference than the applied voltage between the two metal electrodes due to the screening effect of surface trapped carriers. Finally, current hysteretic loops are also observed. The current hysterisis is attributed to the stored charges at the surface or embedded near the surface of the nanodomains, during the scanning phase in the forward direction. The stored charge contributes to the total current, shifting the I-V characteristic as the direction of voltage scanning is reversed.

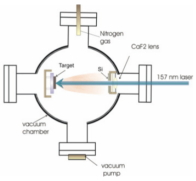
Growth method





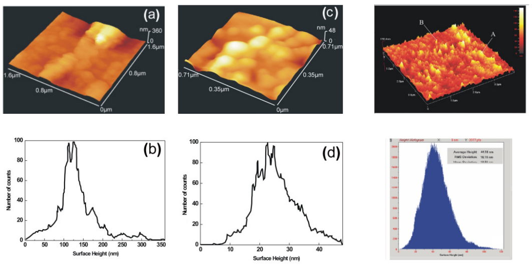
Pulsed Laser Deposition technique

- F_2 Laser: 157 *n*m, 20 *mJ*/pulse, 15 *ns*, 15 *Hz*
- Targets: In and Au
- Substrate: Si
- Distance between target and substrate: 0.3 *cm*
- Background gas: N_2 10^5 *Pa* (1 *atm*)
- Growth rate of the film : 170 *nm/h*



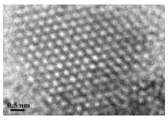
Evaluation of morphology and roughness of the films

AuN$_x$ island **AuN$_x$ granular nanostructures** **InN nanostructures**



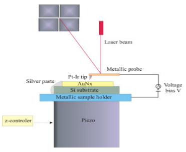
- Atomic Force Microscope (AFM, Bruker d'innova) tapping-mode, phosphorus-(n)-doped silicon tip radius ~8 *nm*, spring const. 40 *N*/*m*, res. frequency 300 *kHz*
- High Resolution Transmission Electron Microscopy (Jeol JEM-2100 operating at 200 *kV*)

HRTEM of hcp-InN



Conductivity measurements

- C-AFM, (Bruker d' Innova in contact mode, Pt/Ir tip of conical shape with tip radius of ~10 *nm*, spring constant 0.2 *N*/*m* and resonant frequency 13 *kHz*)
- Electrical connection through Ag paste.
- Carrier transport mechanism: Thermionic emission.
- High ideality factors *n* ~ 2.
- Current Hysterisis.

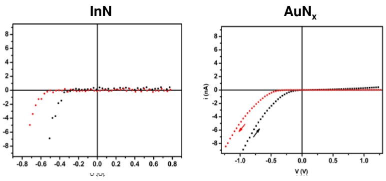


$$I = I_s[\exp(\frac{qV_0}{nkT}) - 1]$$

$$I_s = AA^* T^2 \exp\left(\frac{-q\varphi_b}{kT}\right)$$

$$\varphi_b = \varphi_0 - \sqrt{\frac{qE}{4\pi\varepsilon}}$$

$$E = \sqrt{\frac{2qN_D}{\varepsilon}\left(V_0 + V_{bi} - \frac{kT}{q}\right)}$$



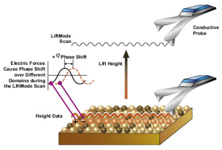
Detection of trapped charges

- Electrostatic force microscopy (EFM, non-contact mode tip-film distance 50 nm)
- Detection of trapped charges via measuring the phase shift of the signal
- Correlation of cantilever's phase shift with the electrostatic force

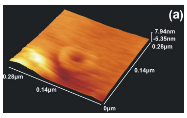
$$\Delta\varphi = \frac{Q}{k_c}\frac{\partial F(z)}{\partial z}$$

- Contributions to the electrostatic force

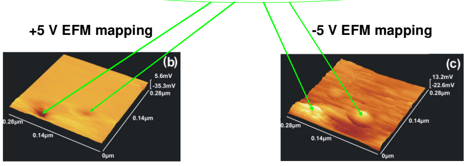
$$F(z) = \frac{1}{(z+\frac{d}{\varepsilon})^2}\left[-\frac{dq_t q_s}{\varepsilon^2 \varepsilon_0 A} + \boxed{\frac{dq_s(V_0 - V_{SP})}{\varepsilon}} - \frac{\varepsilon_0 A (V_0 - V_{SP})^2}{2}\right]$$



AFM image



Presence of accumulated charges



Conclusions

- Semiconducting response of both nitrides:
  - Formation of Schottky nanocontacts
- Rectifying I-V curves:
  - Fitted to thermionic emission mechanism
  - High ideality factors
- Presence of inversion domains:
  - Accumulation of trapped charges
  - Charge memory effects