Local charge carrier transport mechanisms and memory effects in metal (Ta, Au, In) nitride nanostructures

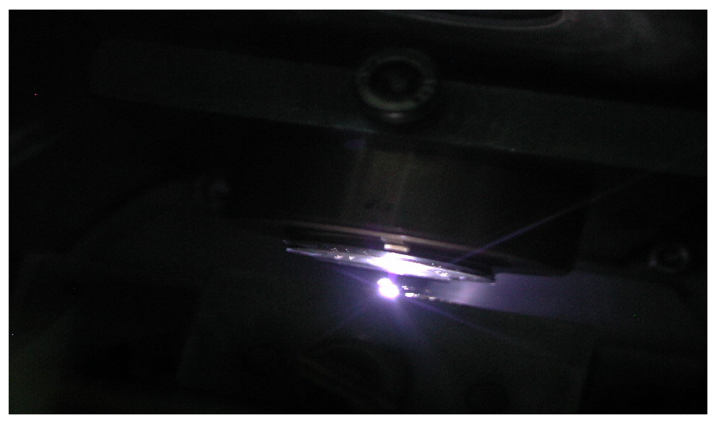
N. Spyropoulos-Antonakakis, E. Sarantopoulou, Z. Kollia and A. C. Cefalas

Theoretical & Physical Chemistry Institute, National Hellenic Research Foundation, Athens, Greece.

Abstract

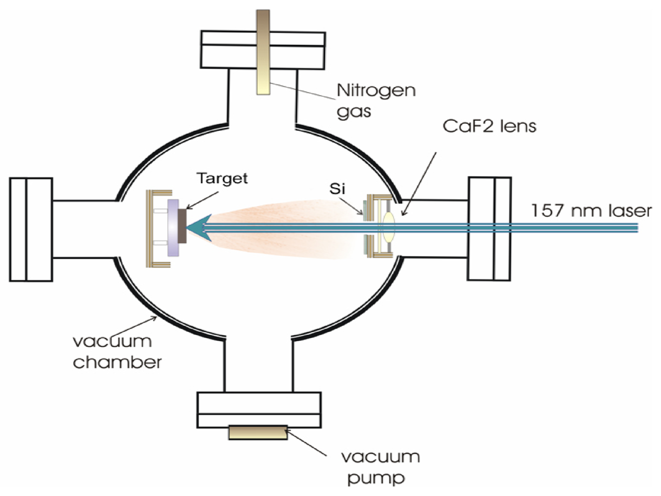
Metal-semiconductor contacts, also known as Schottky contacts, are very important in the functionality of modern electronic devices. Recent progress in the production of high quality materials in the nanoscale has allowed for the development of miniature junctions, further reducing the size and increasing the efficiency of devices such as transistors or memory chips. In this work, the local charge carrier transport properties of TaNx, AuNx and crystalline InN nanostructures deposited on metal coated Si [100] substrates are investigated by conductive atomic force microscopy (C-AFM). C-AFM technique is capable of resolving the electrical properties at the nanoscale, a condition required in the case of inhomogeneous films, where charge transport properties may differ greatly between regions separated by several nanometers. All samples are grown by pulsed laser deposition (PLD) with a molecular fluorine laser at 157 nm in nitrogen environment and at room temperature. By fitting the several charge carrier transport models to the experimental current-voltage characteristics, it is found that the predominant conduction mechanisms are thermionic emission in case of InN, thermionic-field emission in case of AuNx and space charge limited current in case of TaNx nanostructures. Despite the differences in conductivity of the three metal nitrides, all nanostructures exhibit pronounced current hysteresis similar to memory effects. These charge memory effects are attributed to the trapping and de-trapping of charges at the grain boundaries or interstitial defects of the nanostructures, which shift the I-V characteristics as the direction of voltage scanning is reversed.

Growth method



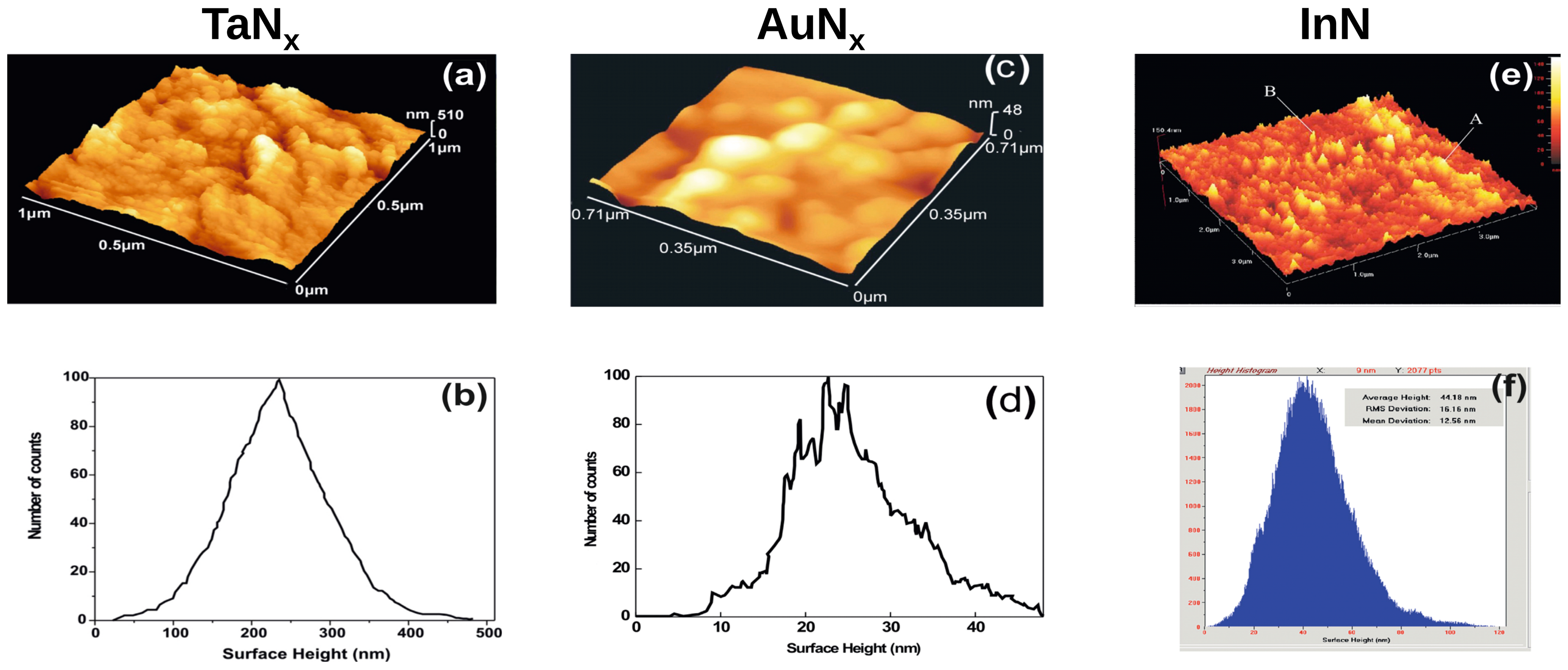
Pulsed Laser Deposition technique

- F_2 Laser: 157 *nm*, 20 *mJ*/pulse, 15 *ns*, 15 *Hz*
- Targets: In, Au, Ta
- Substrate: Si [100] coated with thin Ta or Au layer
- 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

TaN_x | AuN_x | InN



- 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*

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*)

Fitted conduction mechanisms

TaN_x — Space charge limited current

$$i_{SCLC} \propto V^m$$

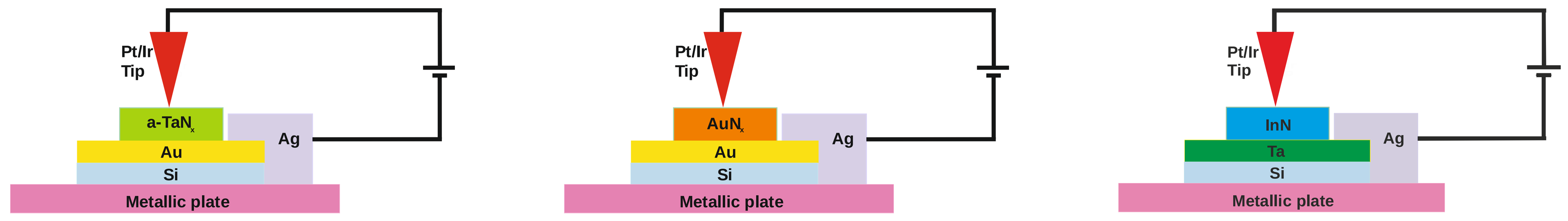
AuN_x — Thermionic field emission

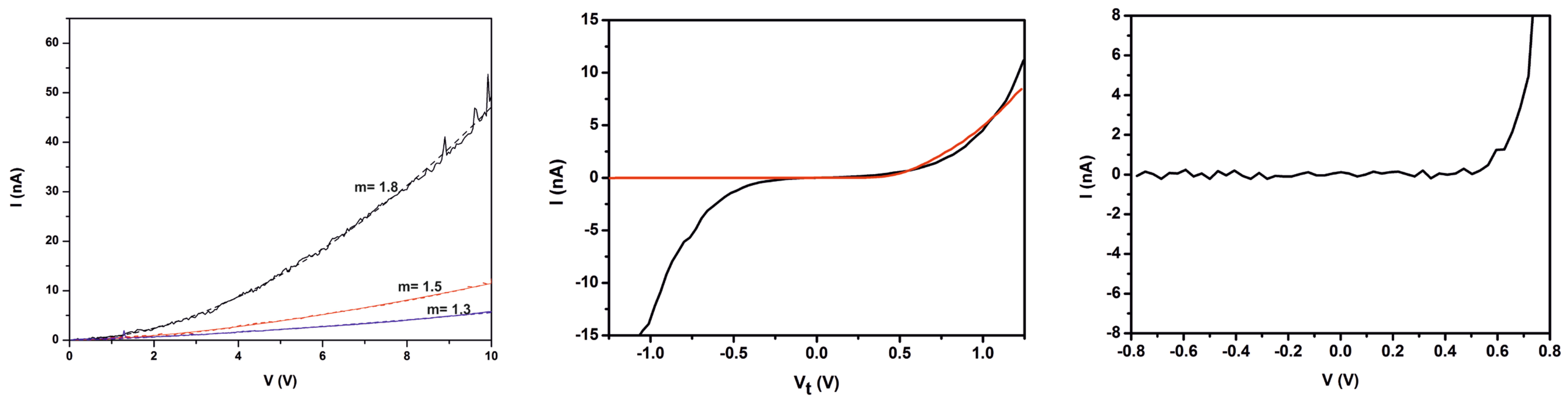
$$i_{FT} = i_s \exp[qV_0(\frac{1}{kT} - \frac{1}{E_{00}\coth[E_{00}/(kT)]})],$$

$$E_{00} = \frac{hq}{4\pi}\sqrt{\frac{N_D}{\varepsilon m^*}} = 18.5\times10^{-15}\sqrt{\frac{N_D}{\varepsilon_s m_c}}\ eV$$

InN — Thermionic emission

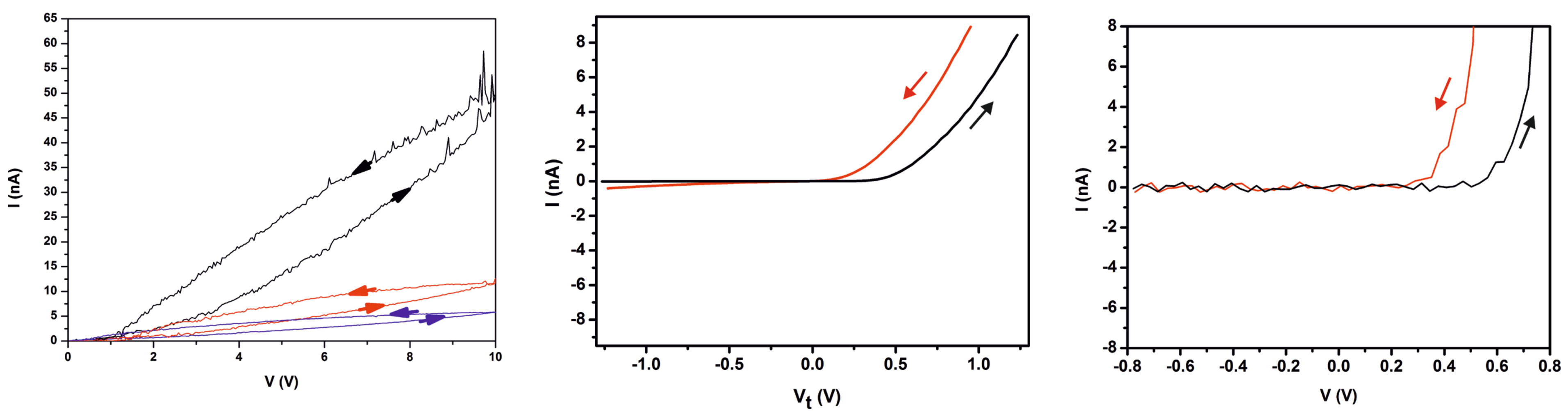
$$i_{FT} = i_s \exp[(\frac{qV_0}{nkT} - 1)]$$





Charge memory effects

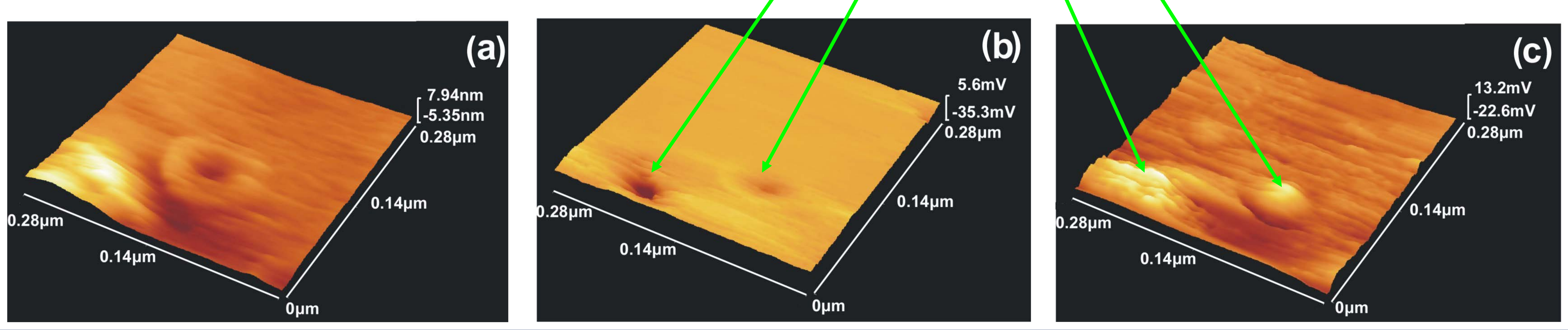
TaN_x | AuN_x | InN



- Electrostatic force microscopy (EFM, non-contact mode tip-film distance 50 nm)

Presence of accumulated charges

AFM image | +5 V EFM mapping | -5 V EFM mapping



Conclusions

- Semiconducting response of the nitrides
- Formation of Schottky nanocontacts

Presence of inversion domains:
- Accumulation of trapped charges
- Charge memory effects