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Nanonets2Sense

Nanonet-based integrated sensors for health and well-being

WP4: Device characterization and modelling

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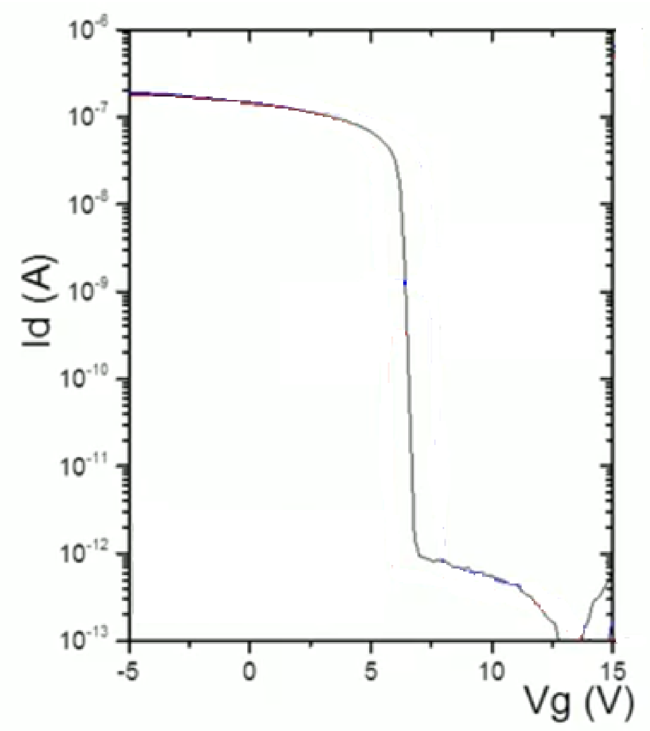
Device characterization and modelling

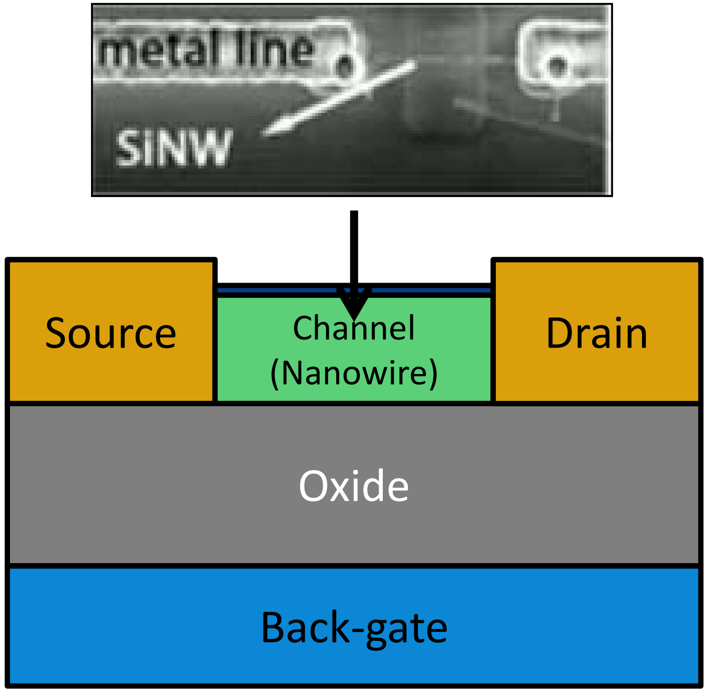
- **FET-based Biosensor Characterization**
- **Electrical Characterization and compact modelling of NN-FET**
- **Physical modelling of NN-FET**

FET-based Biosensor Characterization

FET-based Biosensor Characterization

Si-Nanowire as conduction channel

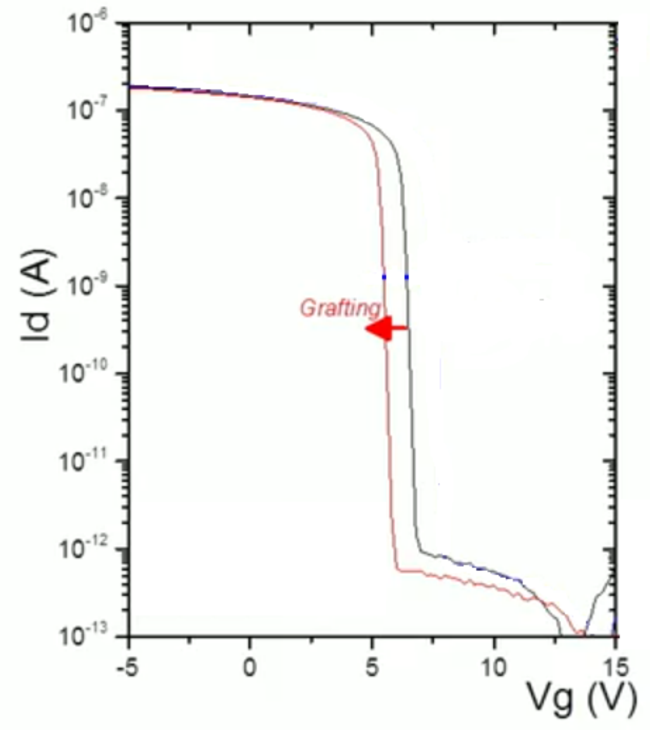


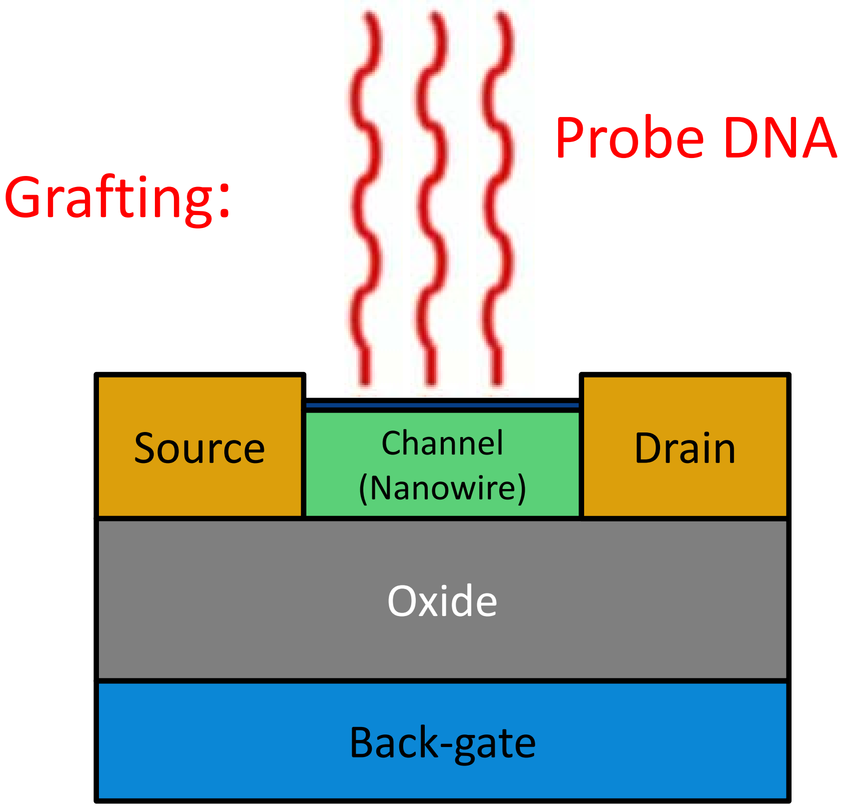


"Fabrication and characterization of high-K dielectric integrated silicon nanowire sensor for DNA sensing application"
G.Jayakumar, M.Legallais, et al., SPIE Nanoscience + Engineering (2016)

FET-based Biosensor Characterization

- **Si-Nanowire as conduction channel**





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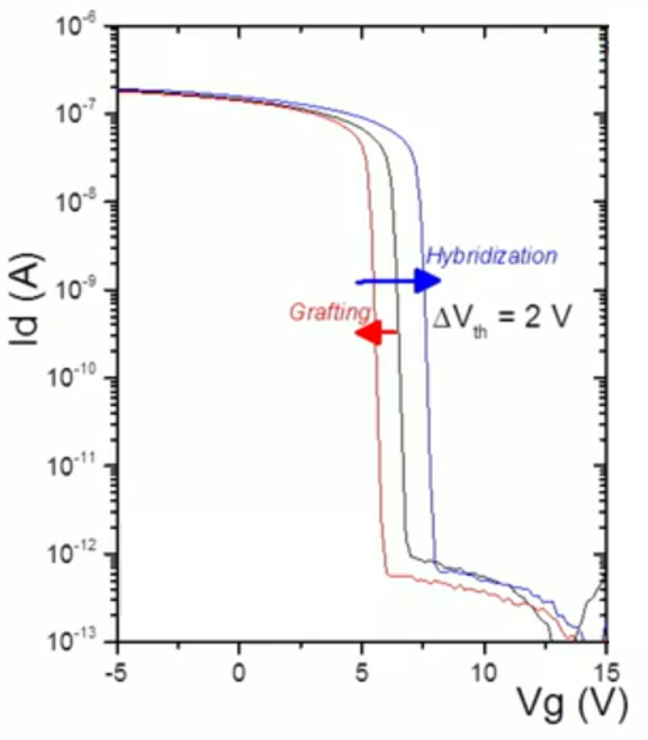
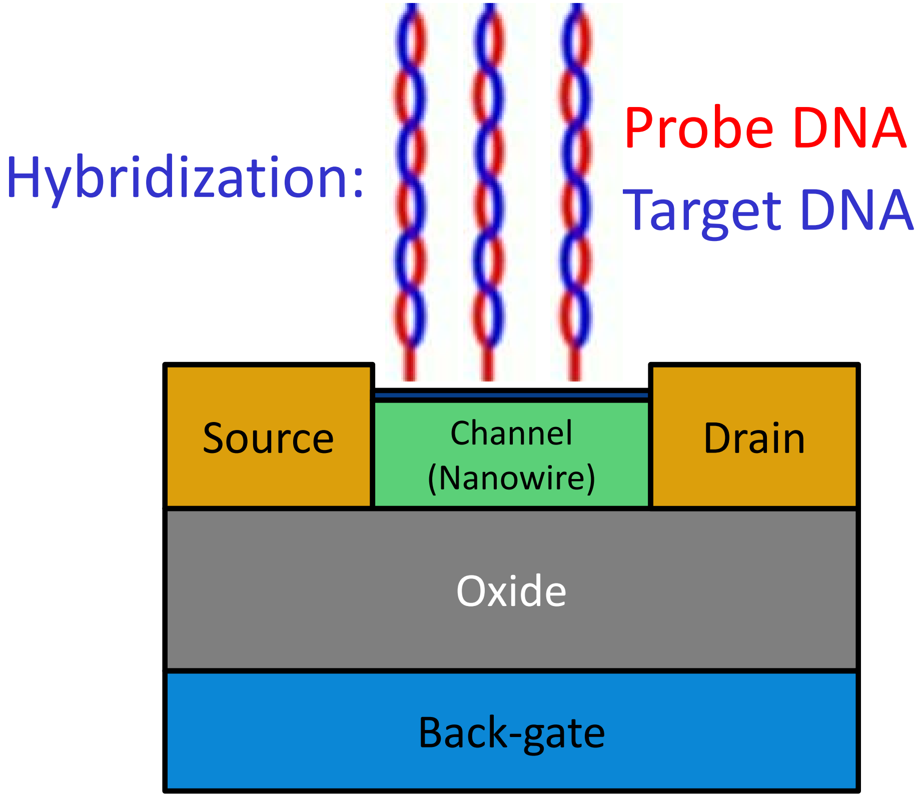
FET-based Biosensor Characterization

▶ Si-Nanowire as conduction channel




Hybridization:

Probe DNA

Target DNA

Source

Channel
(Nanowire)

Drain

Oxide

Back-gate

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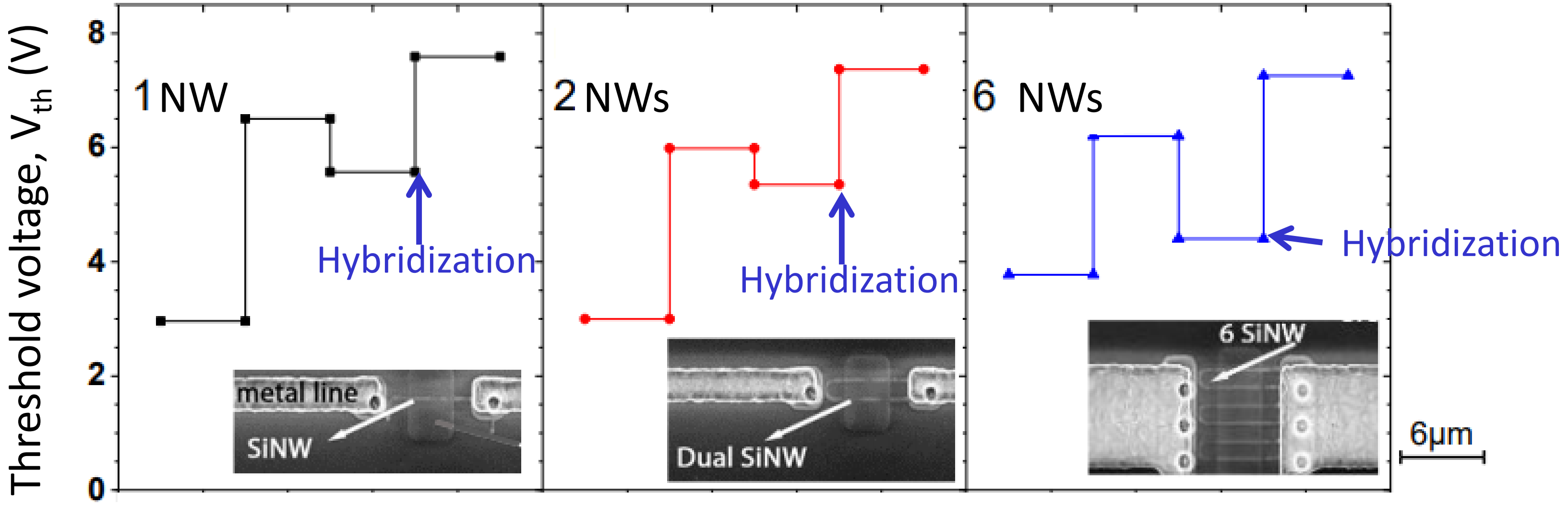
Results

- **Measurable Threshold Voltage variation during hybridization**



- **Next step: FET-based biosensor with Si-Nanonet as channel**

Electrical Characterization of NN-FET

Devices geometries and characteristics

Nanowires

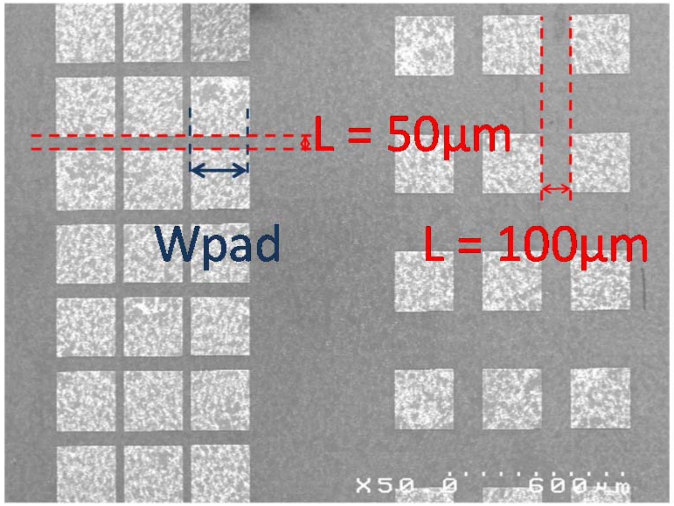
- Length = 6.9 µm ± 2.8 µm
- Diameter = 39 nm ± 7 nm

Nanonet Fabrication

- NWs density = $0.18\ \text{NW}/\mu\text{m}^2 \rightarrow 0.75\ \text{NW}/\mu\text{m}^2$

Devices geometries

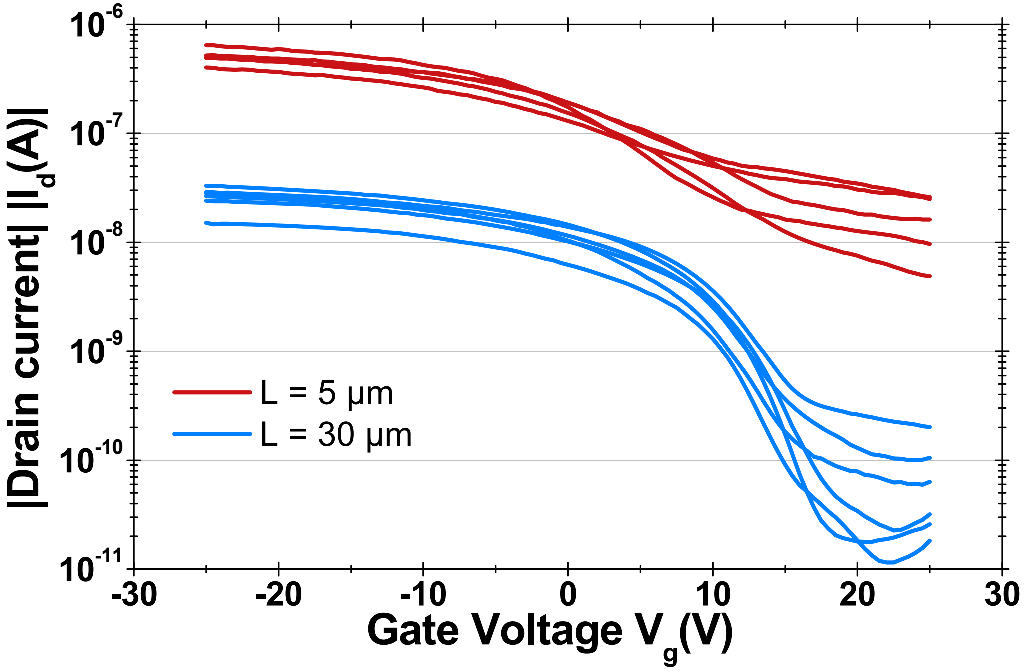
- Nanonet on Si/Si_3N_4(200nm) Wafer
- Substrate used as back-gate
- Channel Length L= 5 µm → 1000µm
- W_{pad} = 200 µm



Gate characteristics measurements

- **Up to 20 devices for each channel length and density**

Constant density = 0.53 wires/µm²



- **Functionality as p-FET device is demonstrated**
- **Correct turn-on behaviour**
- **Visible variation of electrical characteristics with channel length (and density)**

Compact Model

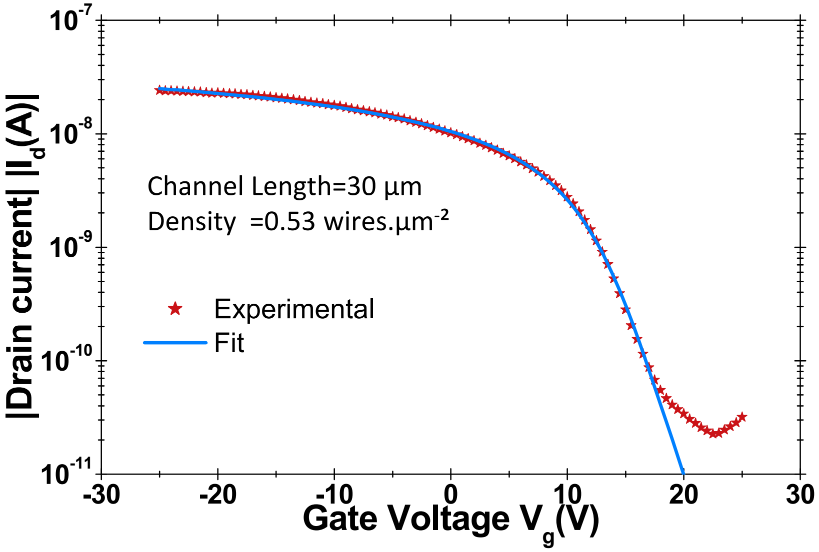
Utility of Compact Modelling

- Summarize the behaviour of NN-FET with a reduce number of parameters
- Compare the quality of 2 different sets of NN-FET (for optimization)
- Understand the physic of the NN-FET (if the electrical parameters have a physical meaning)

Parameters extracted

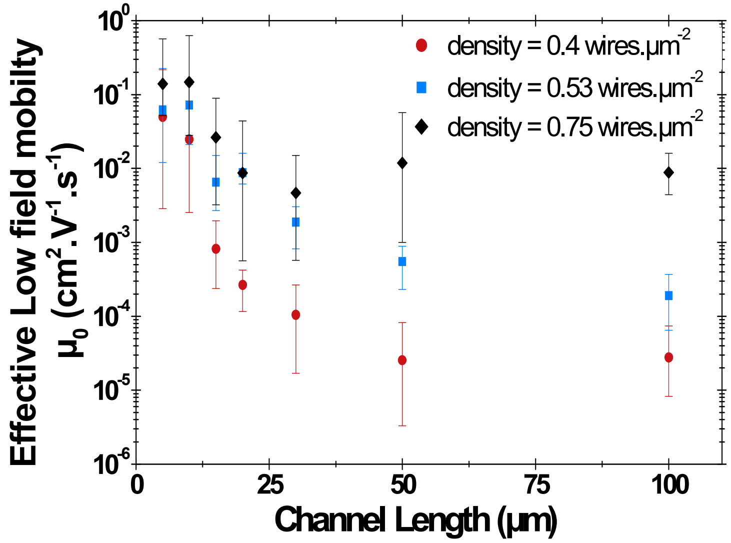
- **Based on Lambert W function**
- **Extraction of the main electricals parameters:**
  - Effective Low-field mobility μ_0
  - Subthreshold slope ideality factor n
  - Threshold Voltage V_{th}

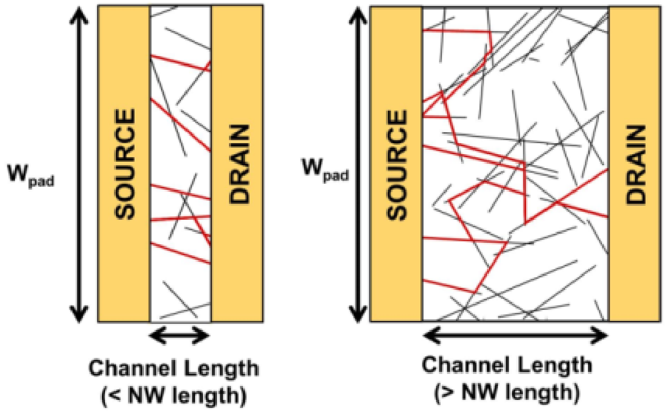
$$Slope = \frac{q}{kT}\frac{1}{n}$$



- **Good fit obtained on most devices**
- **μ_0 has to be normalized with $W_{physical}$ and $L_{physical}$**
- **Assumption for extraction: $W=W_{pad}$**

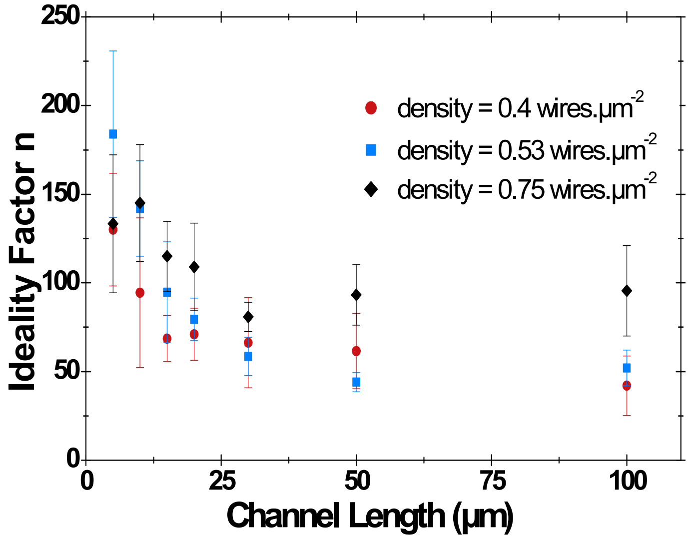
μ_0=f(L) for different NW densities

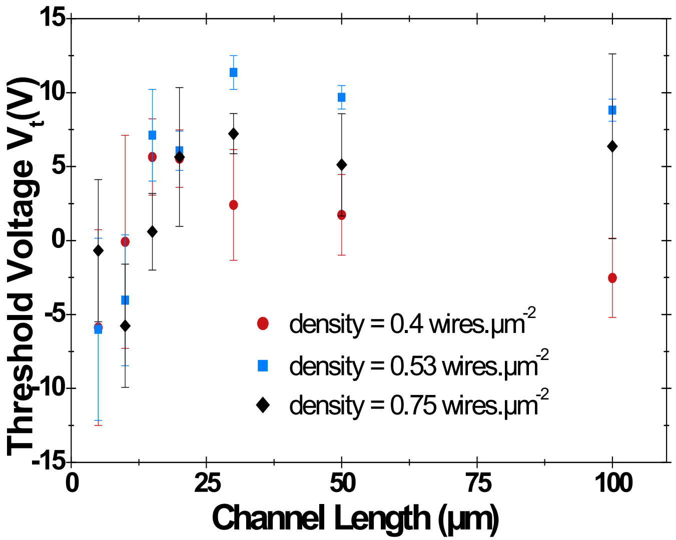


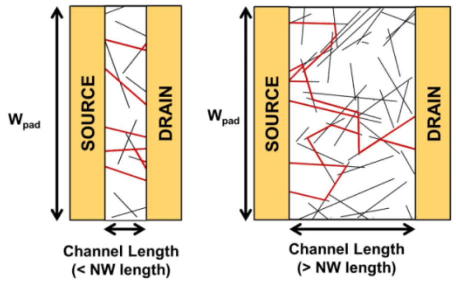


- $W_{physical}$ = f (NW density, L, NW diameter) << W_{pad}
- From short L to long L => µ0 ↘ (because of conduction through junctions)
- For short L, density dependence explained by variation of $W_{physical}$
- Long L : density dependence explained by emergence of more efficient conduction channel

n and V_{th}=f(L) for ≠ NW densities







- **For short L, NWs in parallel with a dispersion of the threshold voltage of individual NWs (V_{th_NW}):**
  - V_{th} of the NN = that of the NW with the more positive V_{th_NW}
  - n↗ : progressive turn-on of the several NWs as V_G decreases
- **For long L, NWs in series:**
  - V_{th} of the NN = that of the NW with the more negative V_{th_NW} along a conduction path
  - n of NN = that of the NW with the more negative V_{th_NW}
  - Reduced dispersion

Conclusions

- **NN-FET functionality as p-FET is demonstrated**
- **Good fit of the Id-Vg obtained with compact model**
- **Variations of electrical parameters with channel Length and density can be explained**