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Electric Field Effect in Ultra-thin TiN Films

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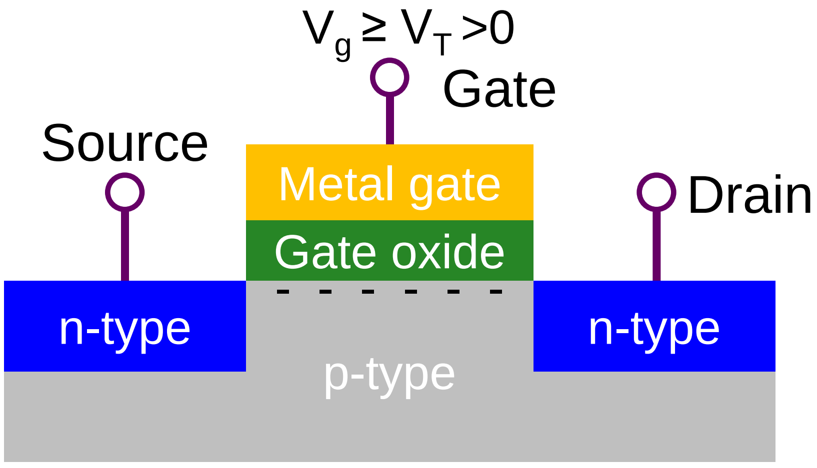
Ref.: H. Van Bui et al., APL, 103, 051094 (2013)

Introduction

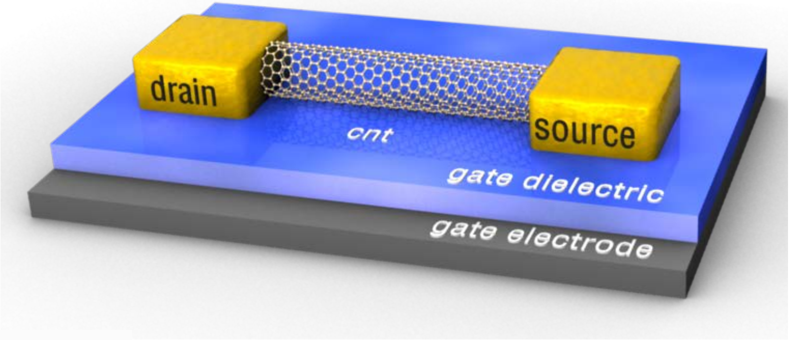
- Electric field effect: ability to modulate the electronic transport properties of a material by an external electric field.

→ field effect transistors (FETs)

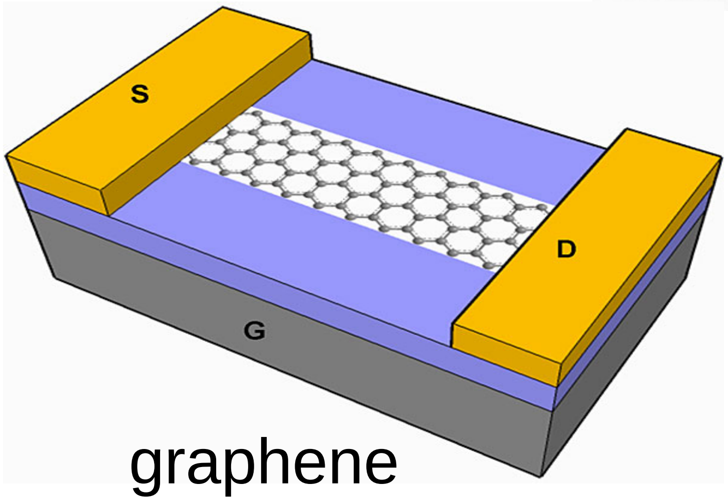


Conventional FET

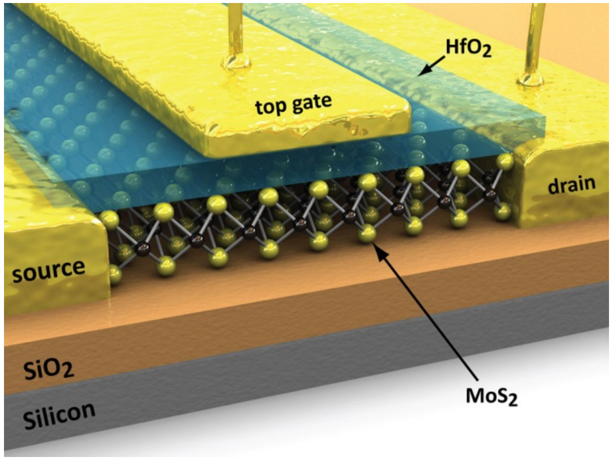
Introduction



Carbon nanotubes



graphene



Molybdenum disulfide

Introduction

- Most desirable materials should exhibit conductance close to that of a metal → electric field effect in metals?
- Metals: high electron concentration prevents the penetration of electric field (screening effect)

→ Induced surface charge is negligible compared to bulk carrier concentration.

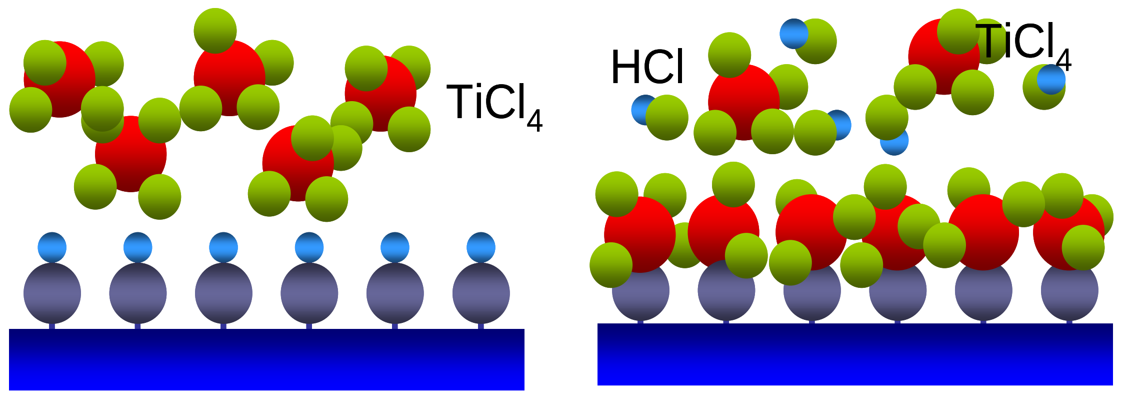
→ To observe field effect in metals: film thickness ~ screening length.

- We use atomic layer deposition to grow ultra-thin continuous TiN films → electric field effect in TiN films

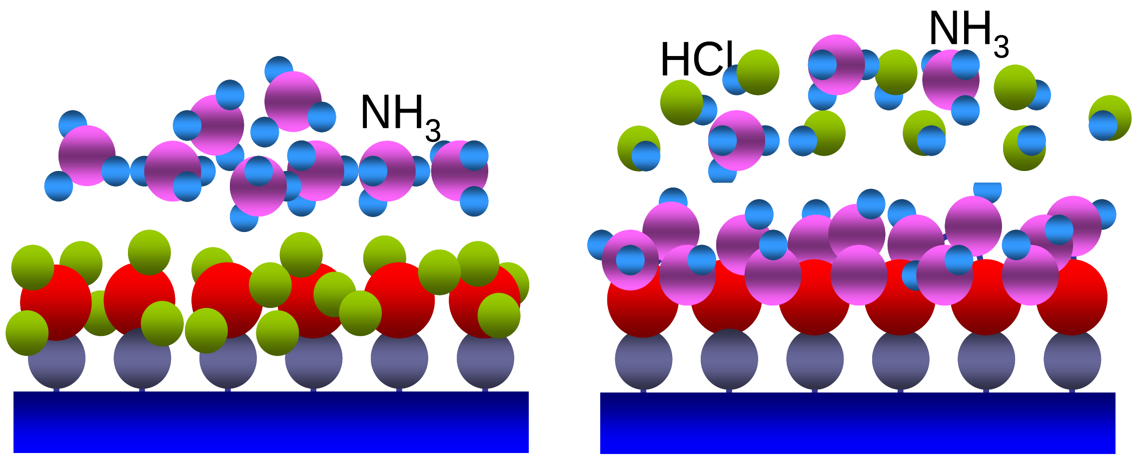
Outline

- *Atomic Layer Deposition (ALD) of TiN*
- *Resistivity and Temperature Coefficient of Resistance (TCR) of ultra-thinTiN films*
- *Electric field effect in ultra-thin TiN films*
- *Conclusion*

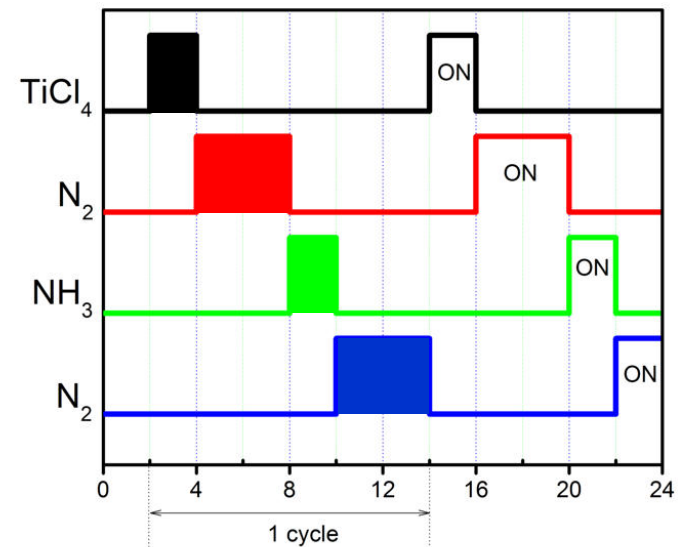
Atomic Layer Deposition of TiN from $TiCl_4$ and NH_3



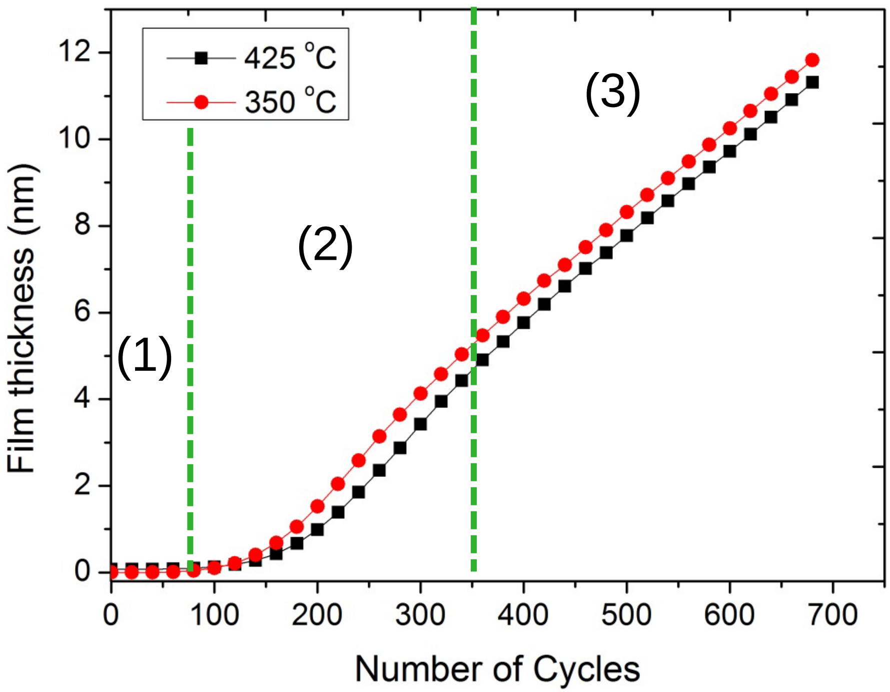
$$-OH + TiCl_4 \rightarrow -OTiCl_3 + HCl$$



$$-TiCl + NH_3 \rightarrow -TiNH_2 + HCl$$



Growth of ALD TiN monitored by *in-situ* SE



(1): Incubation regime

(2): Transient regime

+ 2D growth

+ 2D-3D transition

+ Closure of 3D islands

(3): Linear regime: Film thickness increases linearly with ALD cycles.

By in-situ spectroscopic ellipsometry, the film thickness can be precisely controlled.

H. Van Bui et al., J. Electrochem. Soc. 158, H214 (2011)

H. Van Bui et al., ECS J. Solid State Sci. Technol. 1, P285 (2012)

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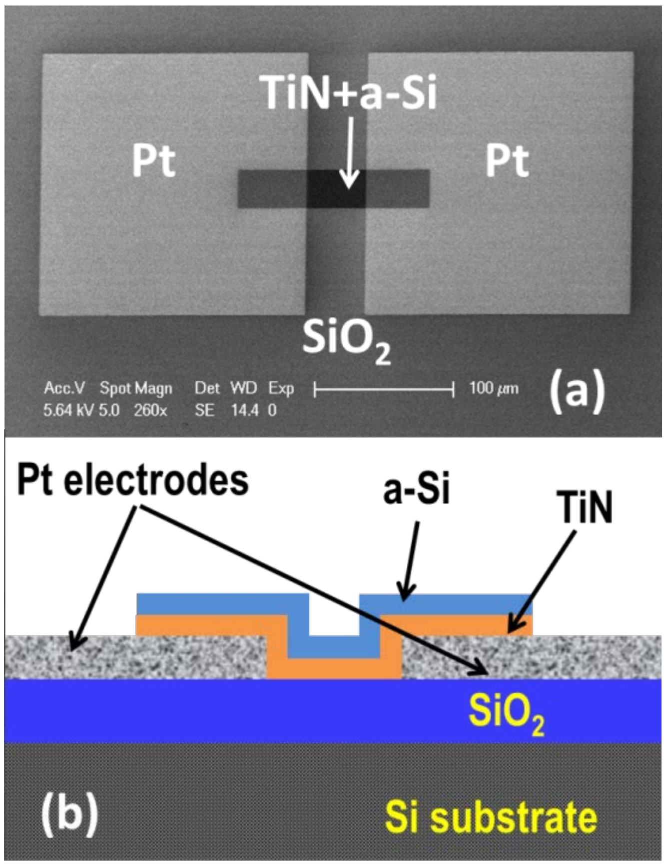
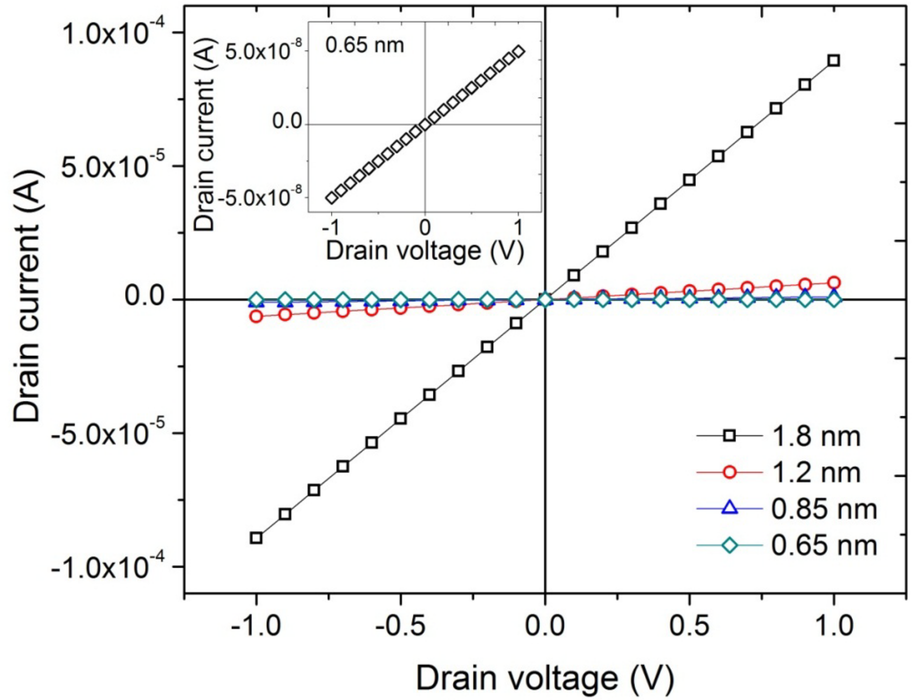
Electrical properties of thin TiN films

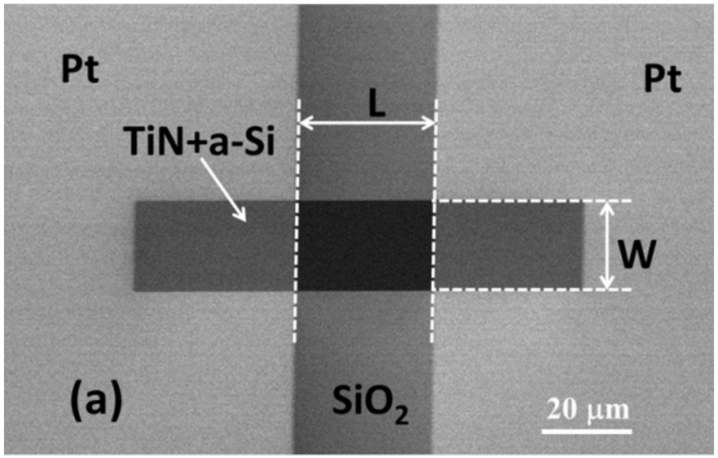
- Test structure

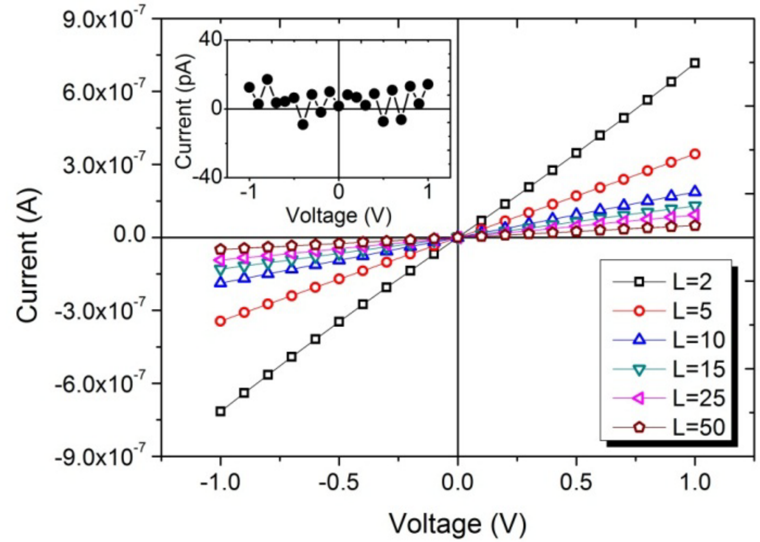




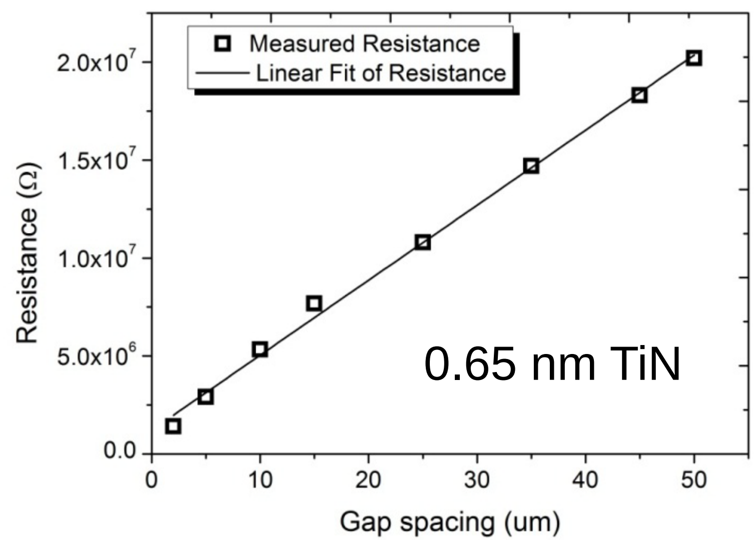
- Linear I-V characteristics → an evidence of continuous films

Resistivity of TiN films



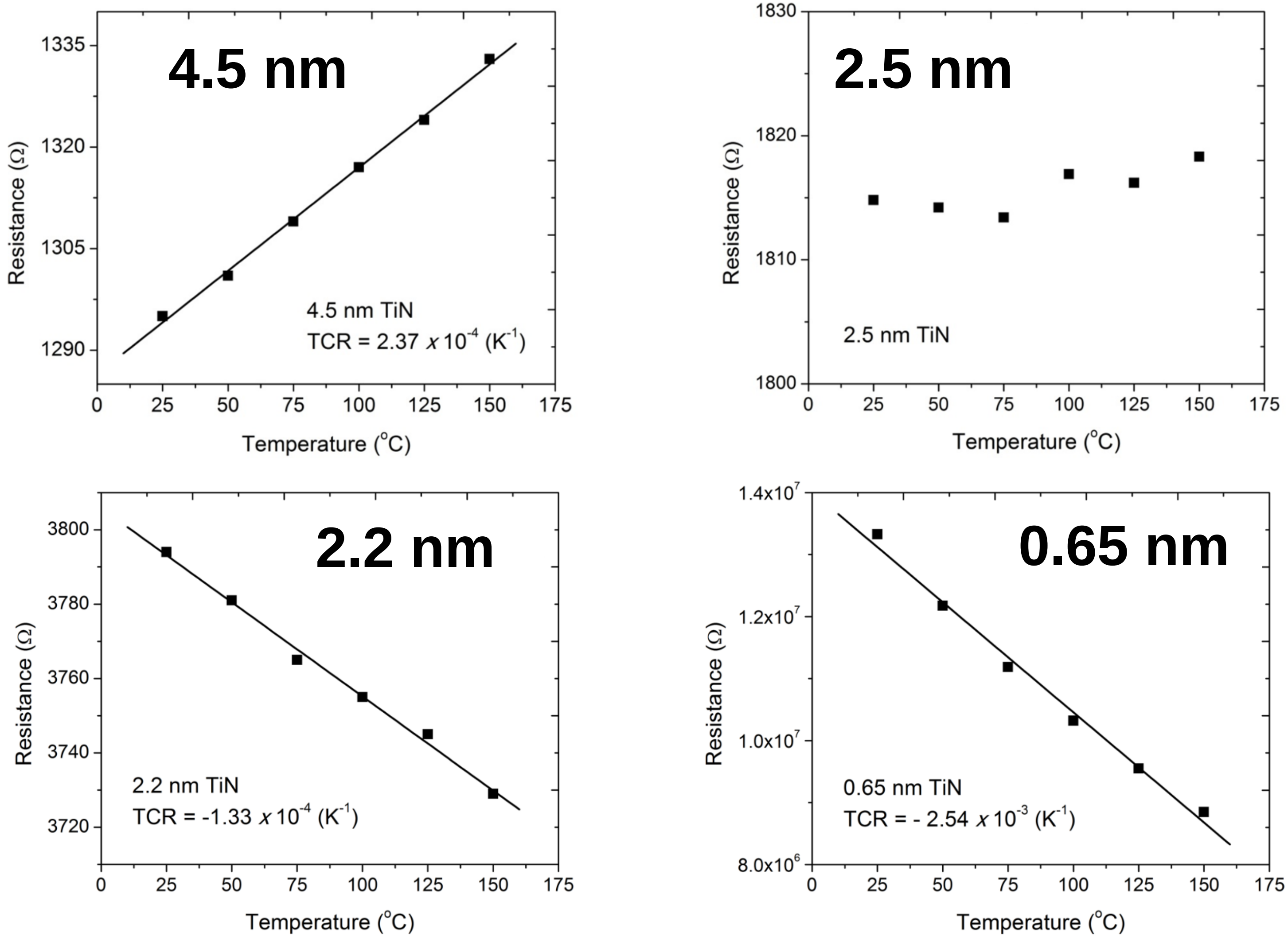


$$R = \frac{V}{I} = \rho \frac{L}{tW} + 2R_c = R_{sh} \frac{1}{W} L + 2R_c$$



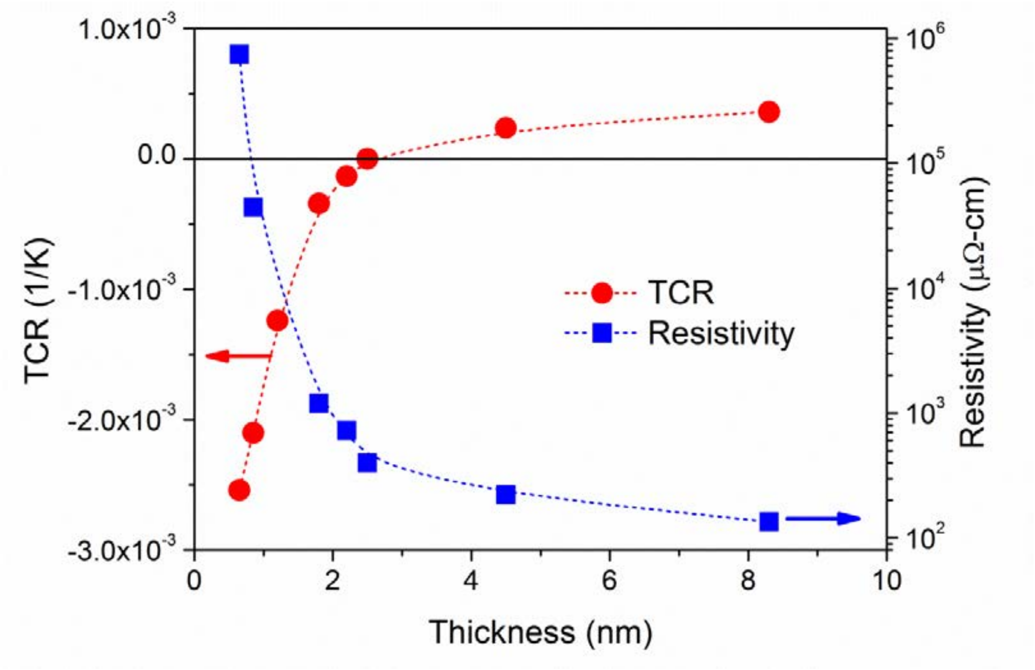
H. Van Bui et al., Appl. Surf. Sci. 269, 45 (2013)

TCR of ultra-thin TiN films



TCR and Resistivity of TiN films - a summary

- Resistivity increases rapidly with decreasing film thickness.
- TCR values change sign at a thickness of ~2.5 nm



Note: TiN films are continuous → TiN films below 2.5 nm are non-metallic

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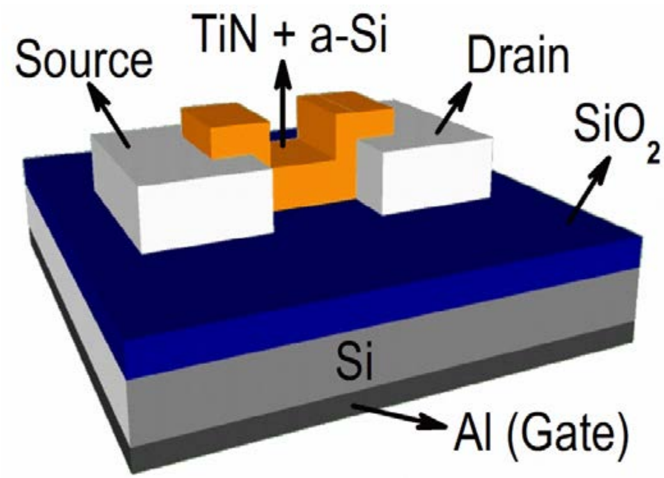
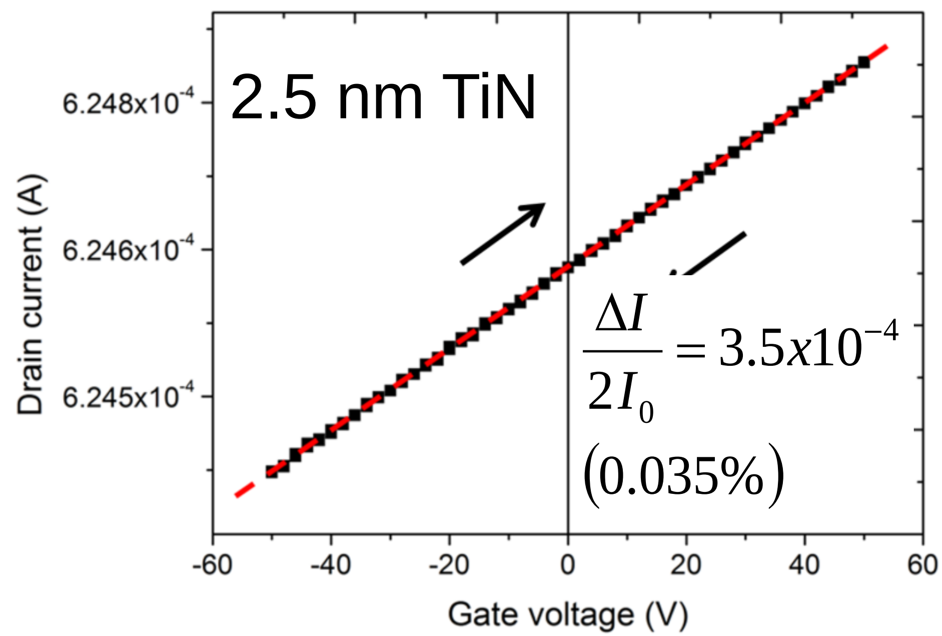
Electric field effect in thin TiN films (I)



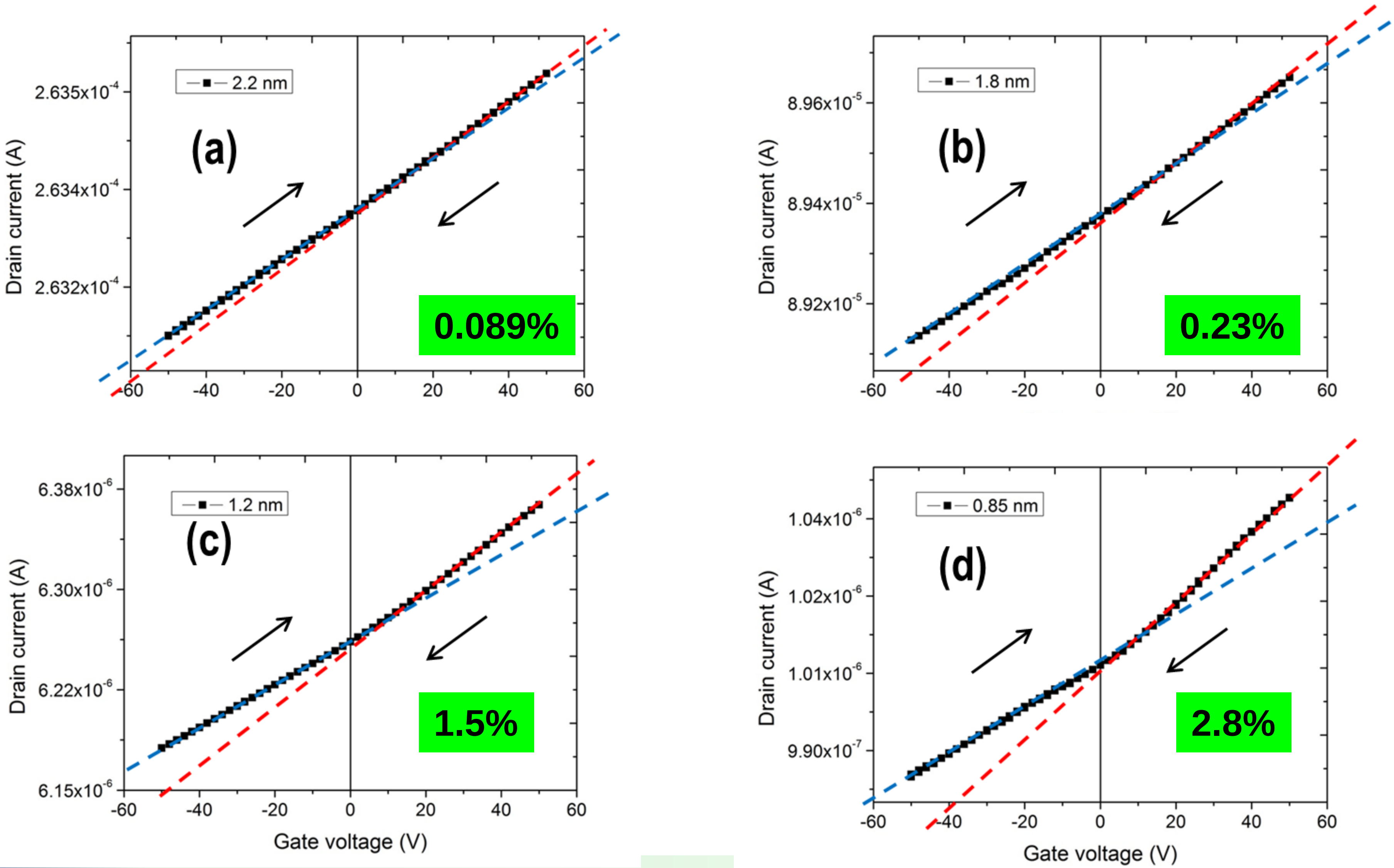
$$\frac{\Delta I}{2I_0} = \frac{I_{V+} - I_{V-}}{2I_0}$$



I_0: current at $V_g = 0$
I_{V+}/I_{V-}: Current at maximum positive/negative gate voltage

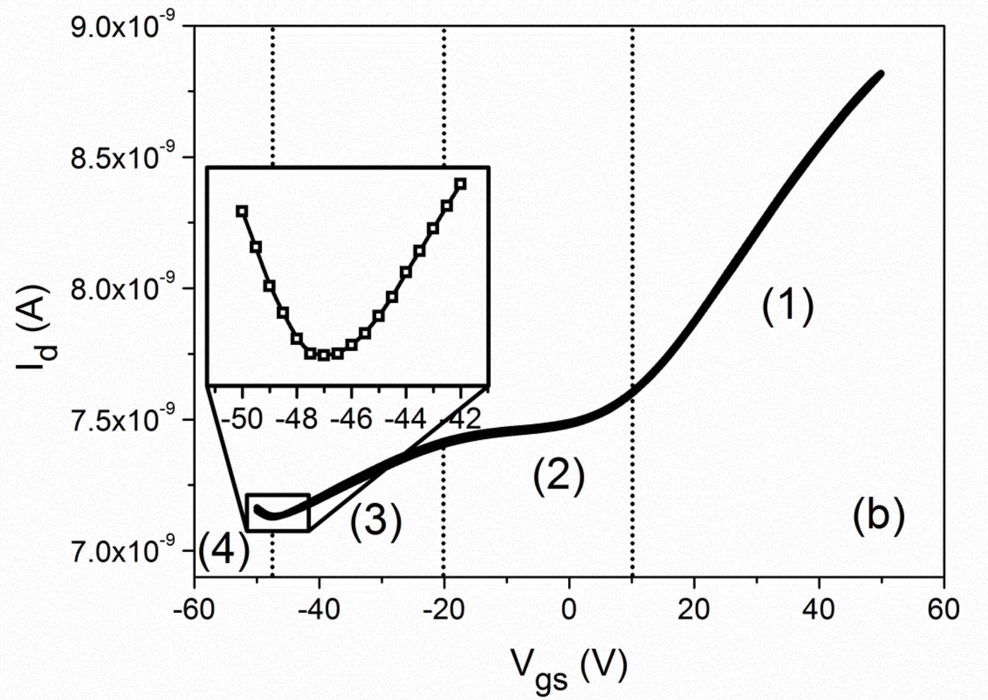
Small field effect is caused by the change of local carrier density and surface scattering.

Electric field effect in thin TiN films (II)



Electric field effect in thin TiN films (III)

0.65 nm TiN



$$\frac{\Delta I}{2I_0} = 11\%$$

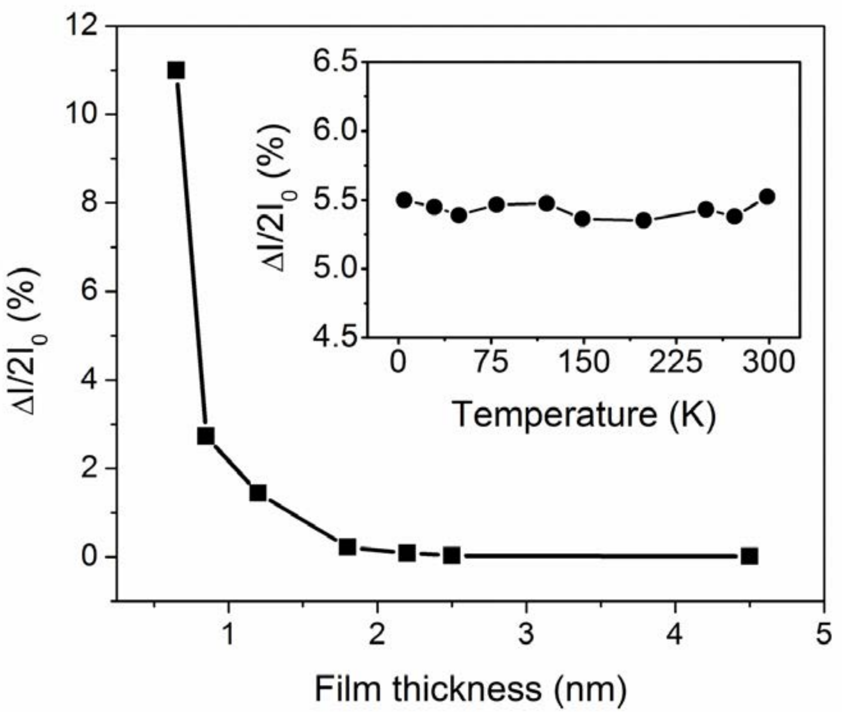
(1) Electrons-only

(2)-(3) Electrons and holes

(4) Holes-only

Coexistence of electrons and holes → Semimetallic state

Thickness and temperature dependence of FE



- The field effect increases remarkably with decreasing film thickness.
- The field effect is temperature independent.

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Conclusion

- Resistivity, TCR and electric field effect in ultra-thin ALD TiN films were studied.
- TiN films below 2.5 nm exhibit semimetallic properties: there co-exists electrons and holes
- Appreciable field-induced current up to 11% in ultra-thin TiN film was obtained. The field effect is temperature independent.

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Thank you for your attention!

Nieuwe technologie mogelijk maken

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