Polarity-dependent reversible resistance switching in Ge-Sb-Te thin films

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OUTLINE

- **Introduction**
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  - **PDR switching at macroscopic-scale**
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INTRODUCTION

Possible future nonvolatile memories

RAM type	Mechanism
P-RAM	phase-change
F-RAM	ferro-electricity
M-RAM	magneto-resistance
R-RAM	electrical-resistance

R-RAM is attractive, utilizing verity of materials including **chalcogenides**

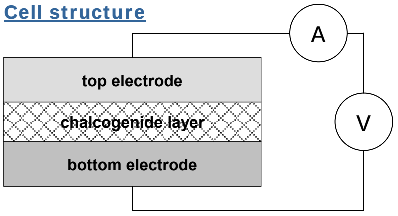
Chalcogenides
- **P-RAM** → resistance switching based on amorphous-crystalline phase-change
- **R-RAM** → resistance switching related to ionic and electronic conductivities

Both Ω-switching mechanisms have been treated separately so far, unified approach would be valuable.

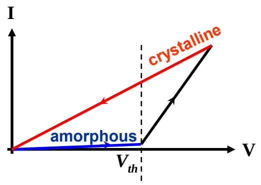
INTRODUCTION

Resistance switching due to phase-change (P-RAM concept)

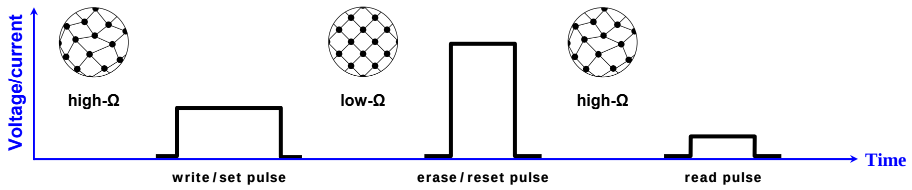
Cell structure



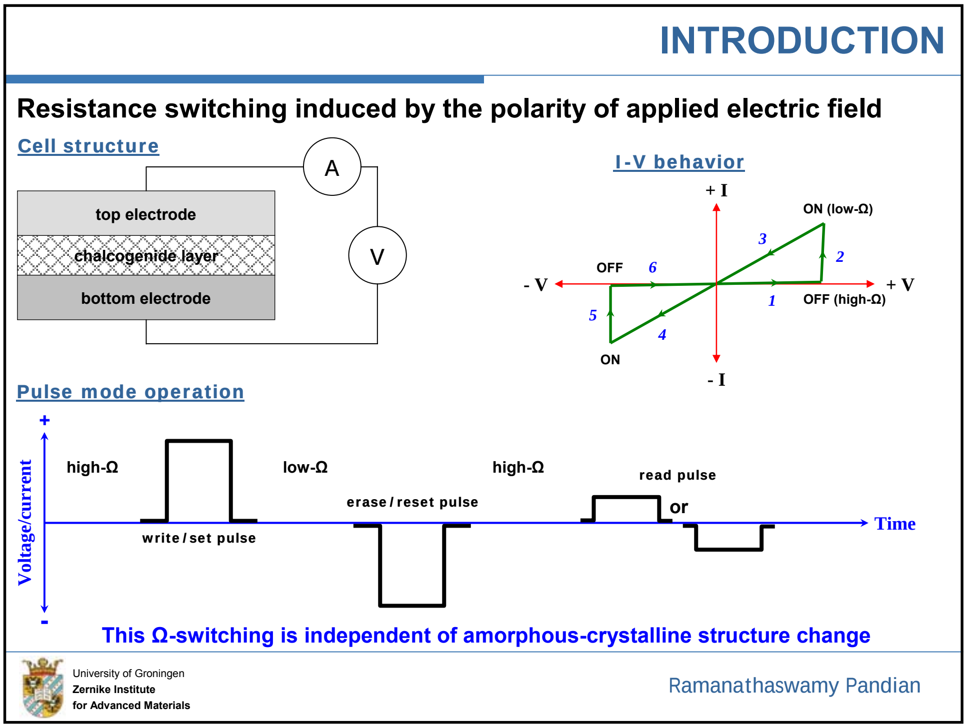
I-V behavior



Pulse mode operation



This Ω-switching is independent of the applied (switching) voltage direction



INTRODUCTION

Resistance switching induced by the polarity of applied electric field

Cell structure

I-V behavior

Pulse mode operation

This Ω-switching is independent of amorphous-crystalline structure change

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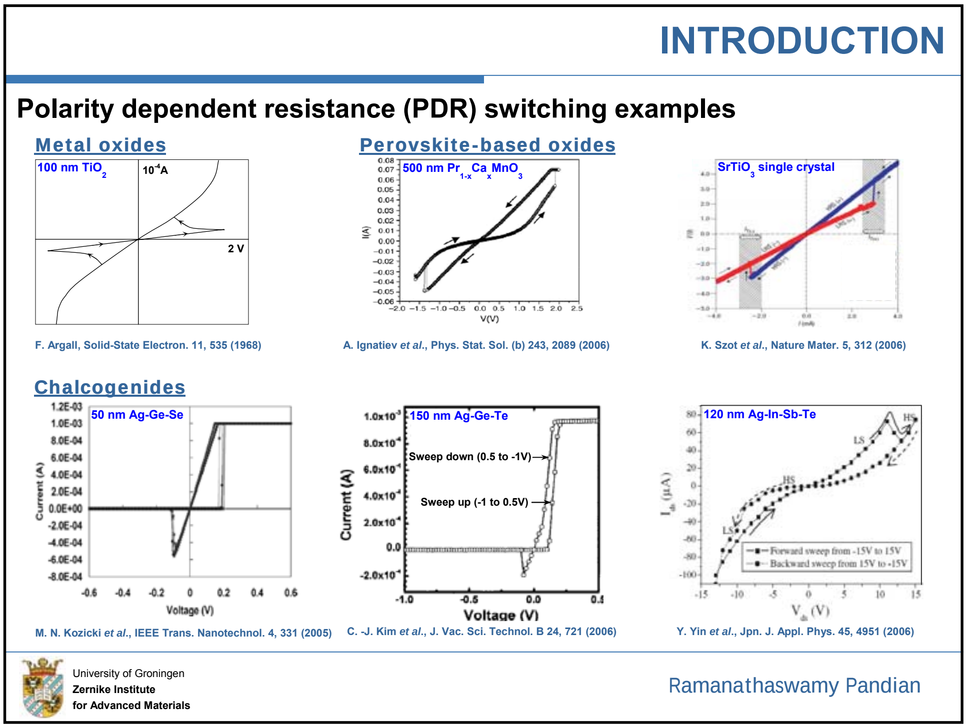

INTRODUCTION

Polarity dependent resistance (PDR) switching examples

Metal oxides

F. Argall, Solid-State Electron. 11, 535 (1968)

Perovskite-based oxides

A. Ignatiev *et al.*, Phys. Stat. Sol. (b) 243, 2089 (2006)

K. Szot *et al.*, Nature Mater. 5, 312 (2006)

Chalcogenides

M. N. Kozicki *et al.*, IEEE Trans. Nanotechnol. 4, 331 (2005)

C. -J. Kim *et al.*, J. Vac. Sci. Technol. B 24, 721 (2006)

Y. Yin *et al.*, Jpn. J. Appl. Phys. 45, 4951 (2006)

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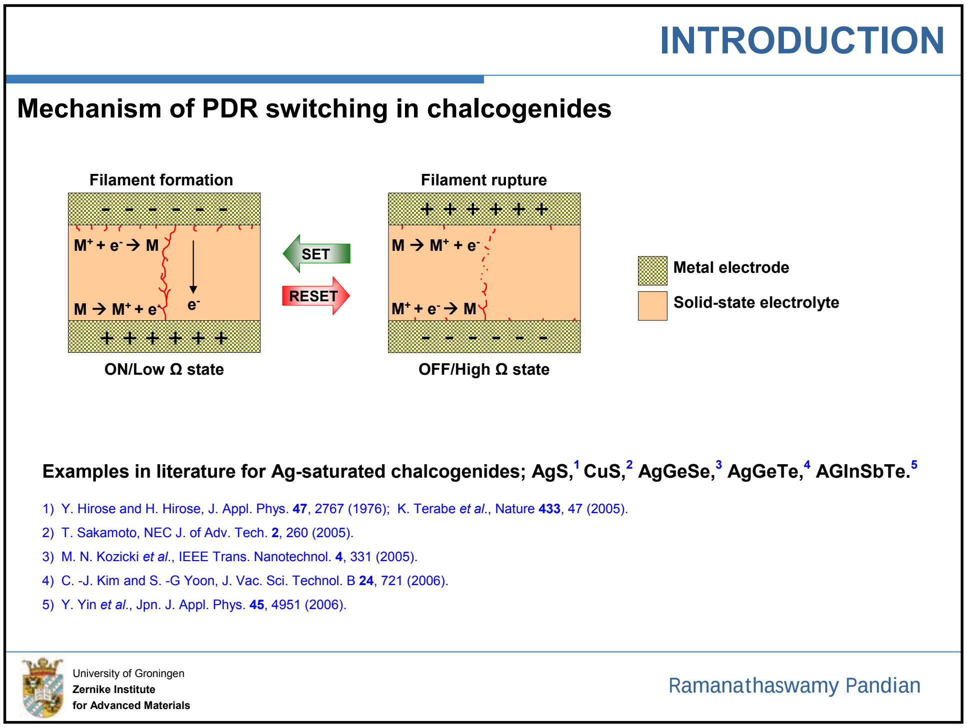
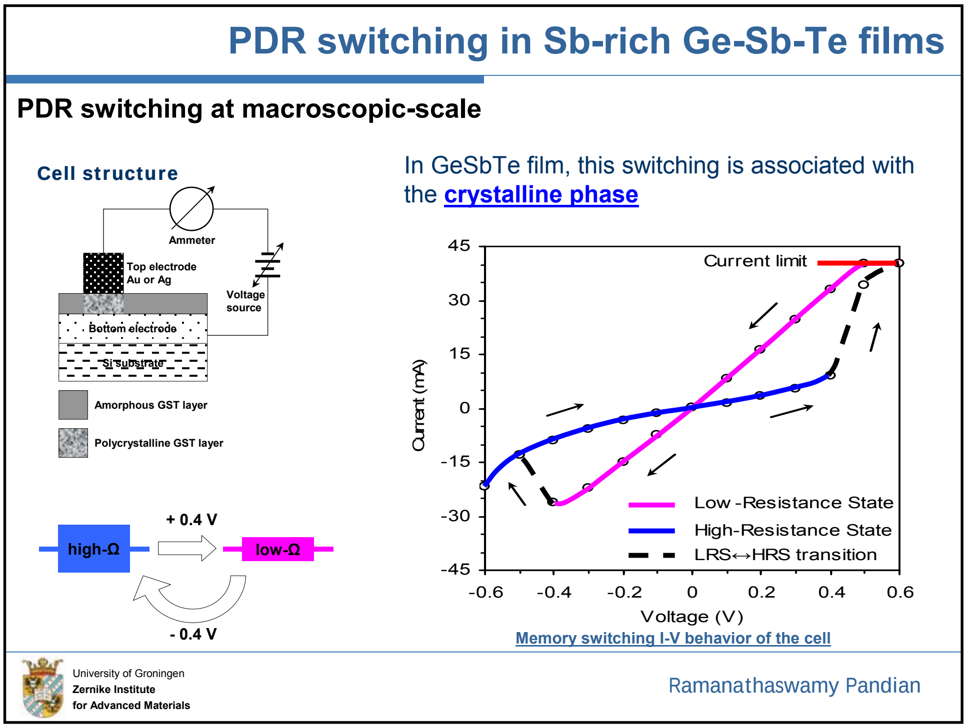


INTRODUCTION

Mechanism of PDR switching in chalcogenides

Examples in literature for Ag-saturated chalcogenides; AgS,[1] CuS,[2] AgGeSe,[3] AgGeTe,[4] AGInSbTe.[5]

1) Y. Hirose and H. Hirose, J. Appl. Phys. **47**, 2767 (1976); K. Terabe *et al.*, Nature **433**, 47 (2005).
2) T. Sakamoto, NEC J. of Adv. Tech. **2**, 260 (2005).
3) M. N. Kozicki *et al.*, IEEE Trans. Nanotechnol. **4**, 331 (2005).
4) C. -J. Kim and S. -G Yoon, J. Vac. Sci. Technol. B **24**, 721 (2006).
5) Y. Yin *et al.*, Jpn. J. Appl. Phys. **45**, 4951 (2006).



PDR switching in Sb-rich Ge-Sb-Te films

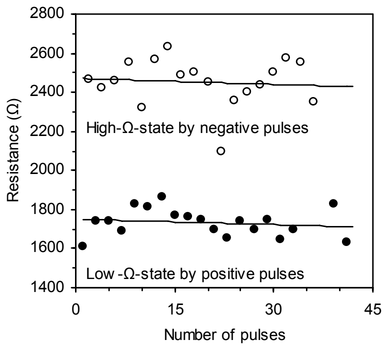
PDR switching at macroscopic-scale

Cell structure

In GeSbTe film, this switching is associated with the **crystalline phase**

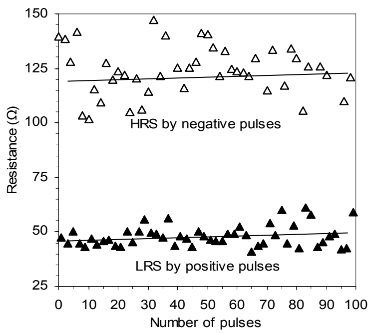
Memory switching I-V behavior of the cell

Two-state PDR switching behavior in a pulse-mode



Sample 1: Ω-switching with ±1.1 V, 500 μs pulses

The contrast is about 40% between the two Ω states



Sample 2: Ω-switching with ±1.25 V, 1 μs pulses

The contrast is about 150% between the two Ω states

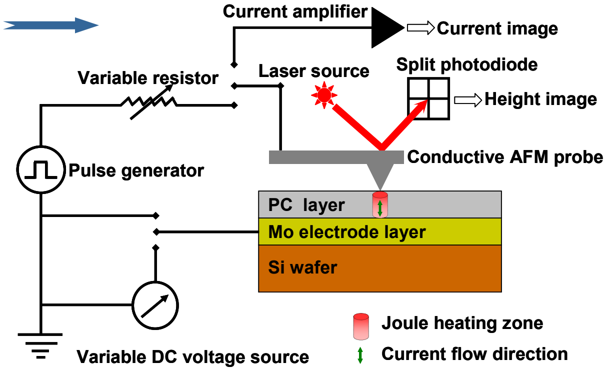
R. Pandian et al., Appl. Phys. Lett. 2007 – under review

C-AFM in resistance switching experiments

AFM is emerging as a powerful tool in data storage

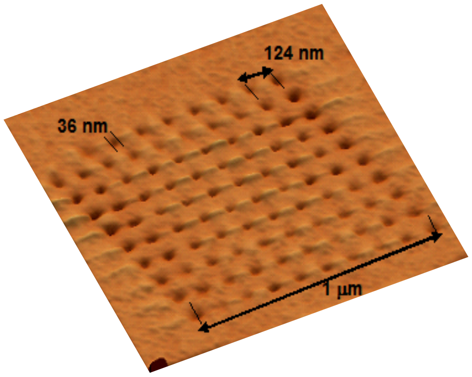
- data writing, erasing, reading is possible
- can produce marks < 10 nm, data density > T.bit/inch^2

C-AFM experimental setup



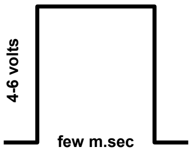
AFM-tip written marks

AFM topographic image



Array of nano-sized crystalline marks
written in 40 nm amorphous Ge-Sb-Te film

Write pulse

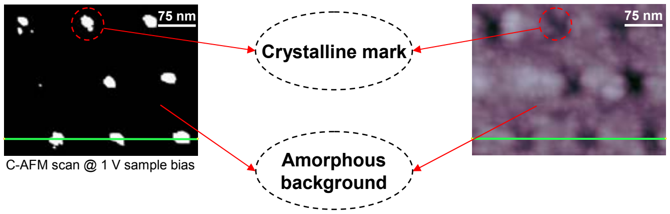


- **Mark size : 20 - 60 nm**
- **Mark spacing : < 125 nm**
- **Mark density : ~ 1 GB/cm^2**

Resistance change due to phase-change

Current image

Height image

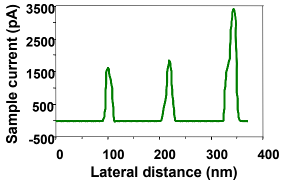


C-AFM scan @ 1 V sample bias

Crystalline mark

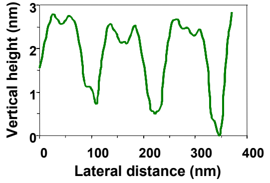
Amorphous background

Current profile



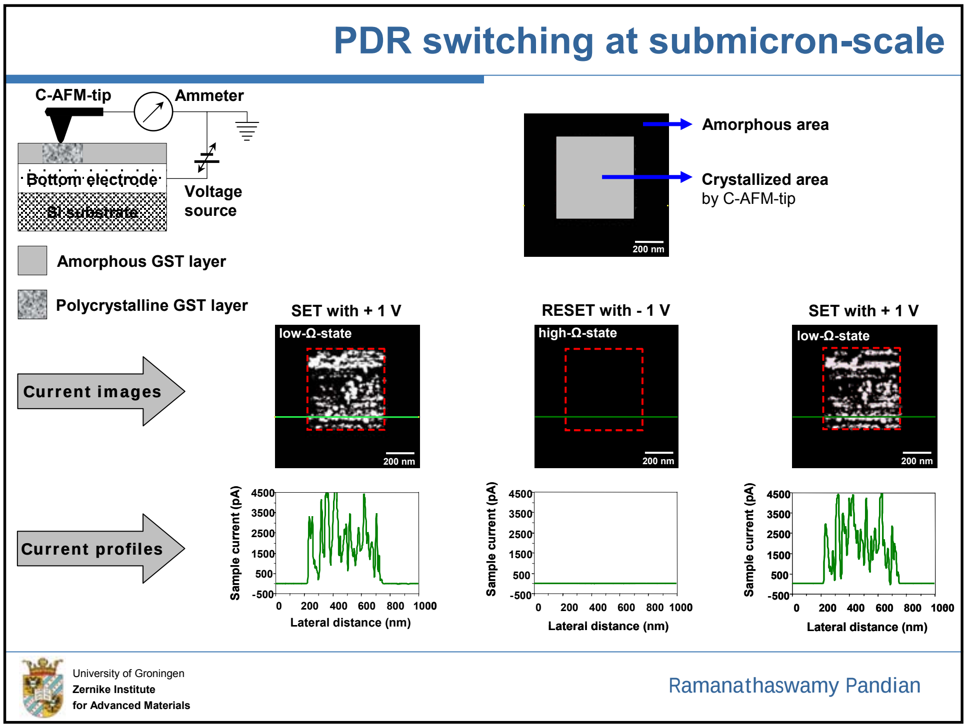
A clear current contrast > 3 orders

Height profile



Height difference ~ 2 nm, is within
the density variation limit of 7-9%*

*W. K. Njoroge *et al.*, J. Vac. Sci. Technol. A 20(1) 2002



PDR switching at submicron-scale

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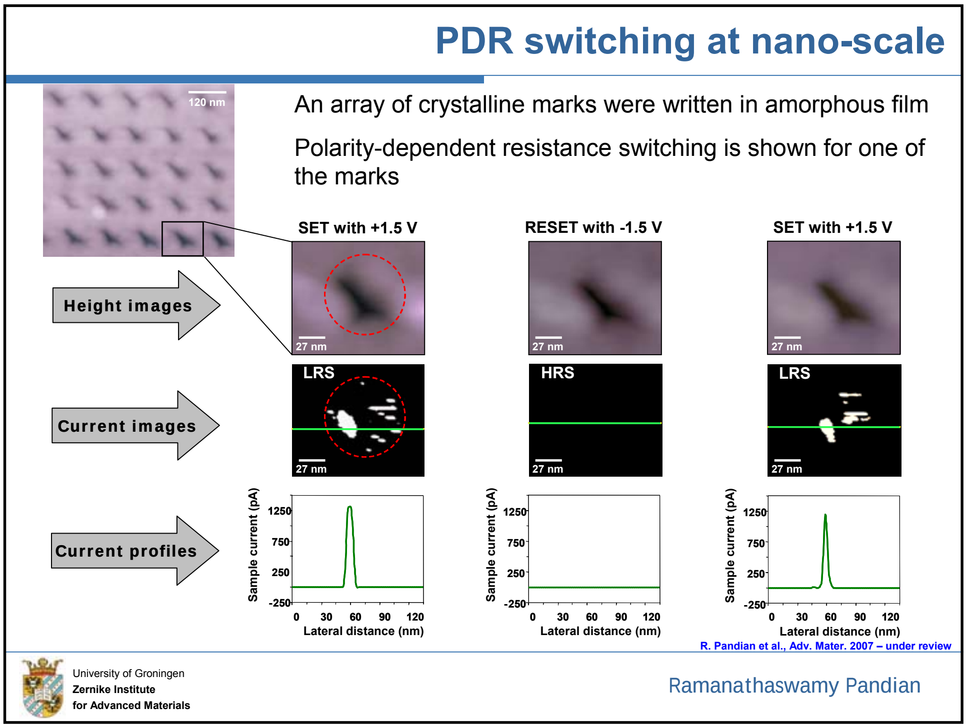

PDR switching at nano-scale

An array of crystalline marks were written in amorphous film

Polarity-dependent resistance switching is shown for one of the marks

R. Pandian et al., Adv. Mater. 2007 – under review

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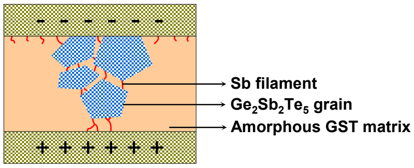
Switching mechanism

- Crystallization, in Sb-excess GeSbTe film, leads to phase separation, where $Ge_2Sb_2Te_5$ nanocrystals form with the excess Sb at grain boundaries[1].
- Crystallites may form near the film surface leaving some amorphous volume near the film-substrate interface[2,3].
- Under electric field, conducting (dendrite like) Sb-filaments could form and bridge the $Ge_2Sb_2Te_5$ grains through the amorphous matrix with the electrodes.
- The conducting Sb-bridges persist until they are dissolved or ruptured by the application of an electric field with reverse polarity.



1) N. Yamada *et al.*, J. Appl. Phys. **88**, 7020 (2000).
2) S. -M. Yoon *et al.*, Jpn. J. Appl. Phys. **46**, L99 (2007).
3) J. A. Kalb *et al.*, J. Appl. Phys. **98**, 054902 (2005);
T. H. Jeong *et al.*, J. Appl. Phys. **86**, 774 (1999).

CONCLUSIONS

- In addition with usual amorphous-crystalline switching, Sb-rich GeSbTe films show polarity-dependent resistance switching. We demonstrated this resistance switching from macro to nanoscales.
- Voltages pulses of amplitudes less than 1.25 V showed the switching within time scales of microseconds with more than 40% resistance contrast, in macroscopic capacitor-like cell structures, for more than a few hundred cycles.
- Using AFM, the switching is possible at nano-scales with even a better resistance contrast of more than 3 orders of magnitude.
- The switching operates with lower threshold limits (<1.25 V) compared to the current ferroelectric and flash memories.