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Perspectives on ReRAM technologies

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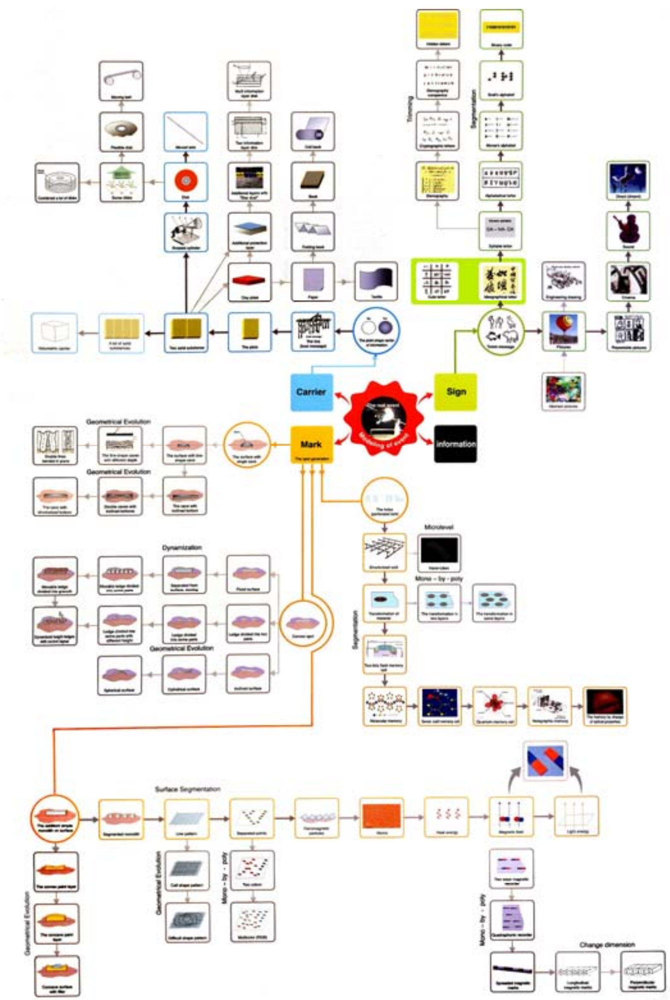
- Evolution patterns of products
- Can we forecast future products?
- Perspectives on ReRAM technologies
- A switching mechanism in ReRAM
- Research suggestions

Patterns of product evolution

Evolution Tree of information storage



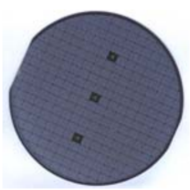
Innovation team, SAIT

Evolution patterns

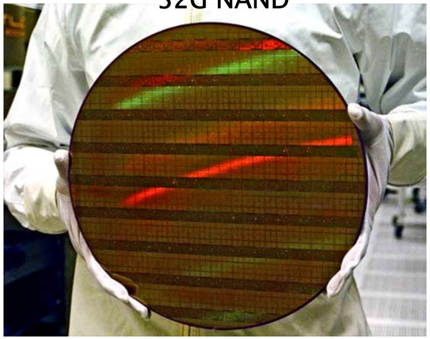
- Dynamization
- Mono-Bi-Poly pattern
- Segmentation
- Geometric evolution
- Substance introduction

⇨ **Increase in entropy**

1G NAND



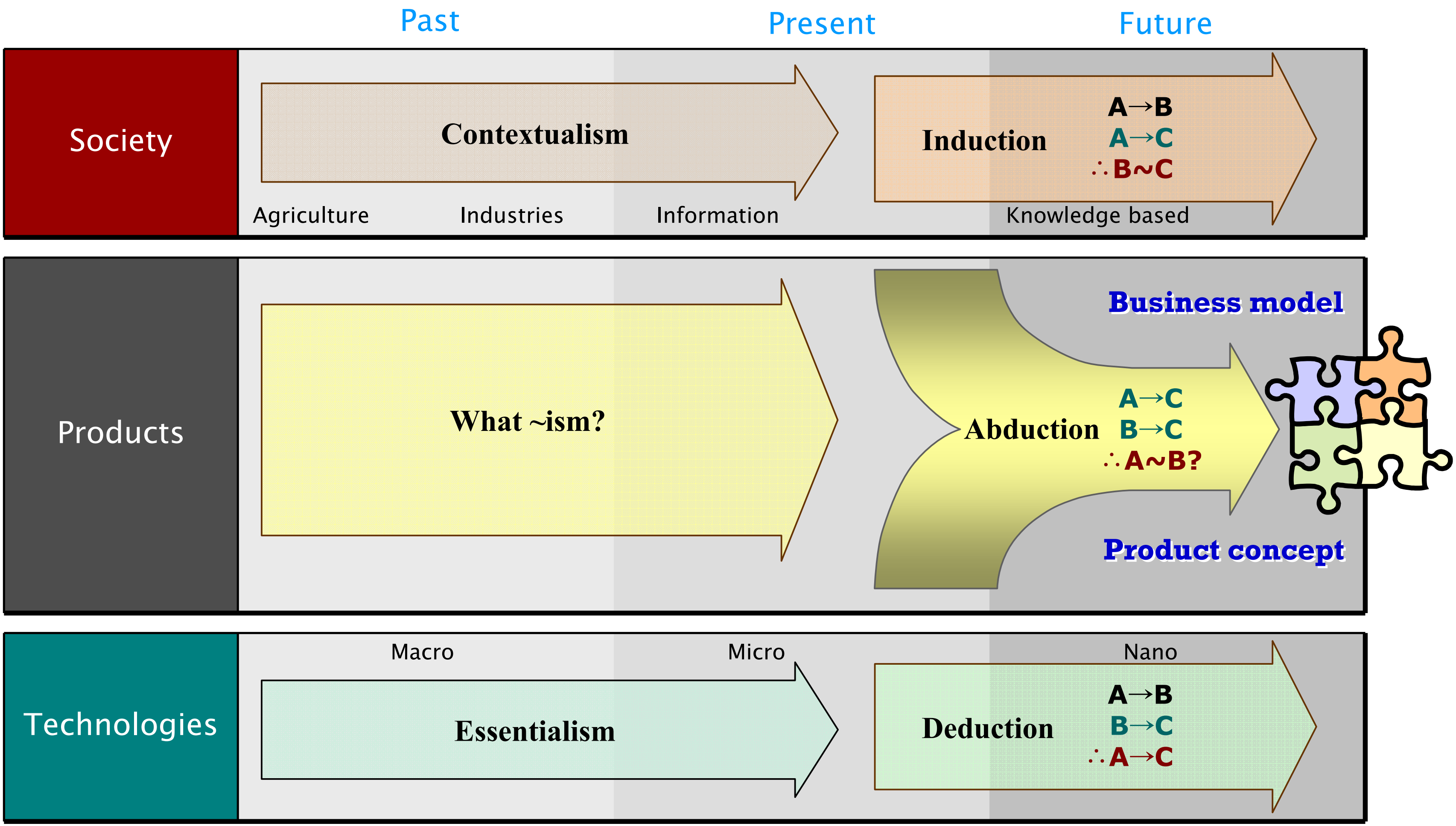
32G NAND



scaling down = segmentation

Can we forecast future products?

Ecosystem should be considered in addition to evolution pattern.
Product concept and business model are neither induced nor deduced, but created.

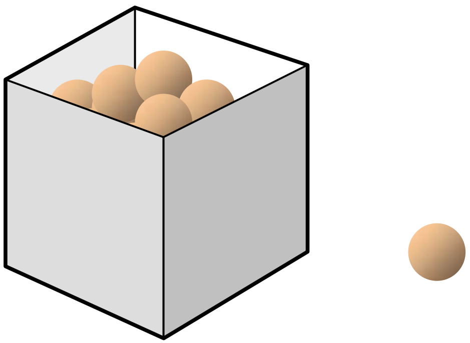


Why abduction?

Deduction : Knowledge is limited

Induction : The conclusion may be wrong

Abduction : Knowledge can be expanded



There are beads in the box on the table.
There is a bead on the table.

Thus,

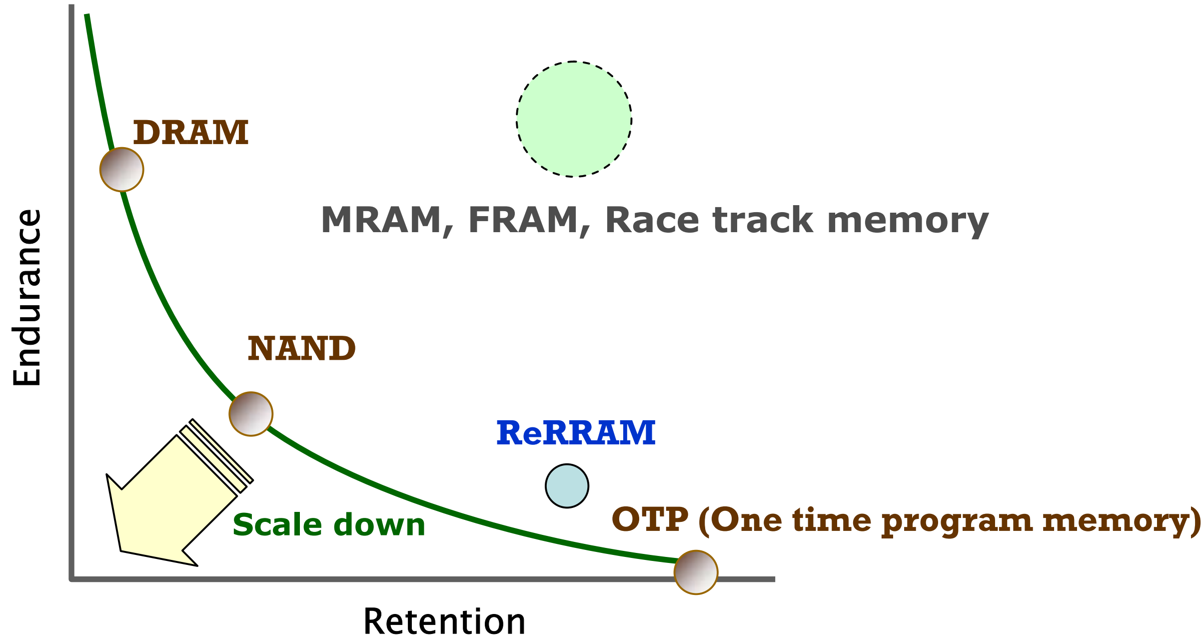
1) The bead might have come out from the box.
2) The bead might have been missed when putting beads in the box.
3) The bead might have been put on the table separately, etc..

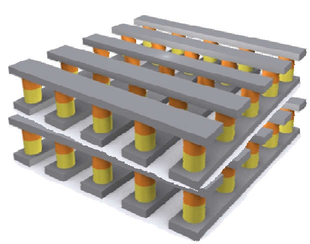
Exercise : What is next? 2015, Global Business Network

1. Find mega trend (Induction)
2. Forecast the final pattern (Abduction)
3. Verify the answer (Deduction)

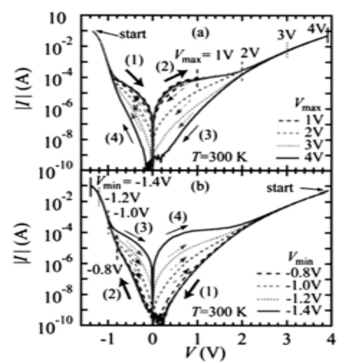
1	1	2	3	3	1	2	3	3
2	3	1	1	3	2	2	1	1
2	3	3	2	2	1	1	3	2
3	1	2	3	1	2	3	1	2
3	1	3	3	2	1	1	3	3
2	2	1	1	3	2	2	1	2
2	3	2	2	1	3			
1	3	1	2	3	2			
3	1	2	3	1	1			

Deductive forecasting memory evolution





Stacked 1D1R ReRAM



Multi level ReRAM

Perspectives on ReRAM

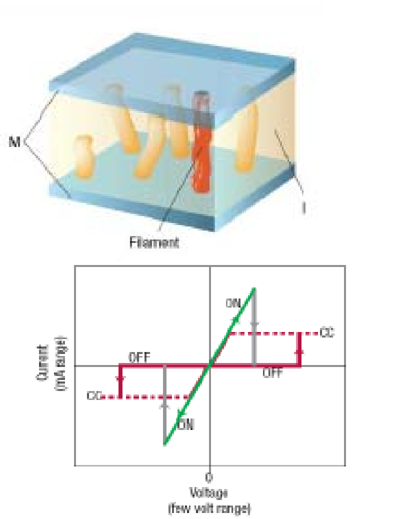
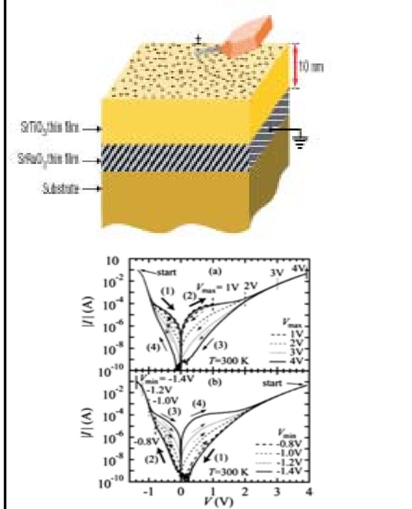
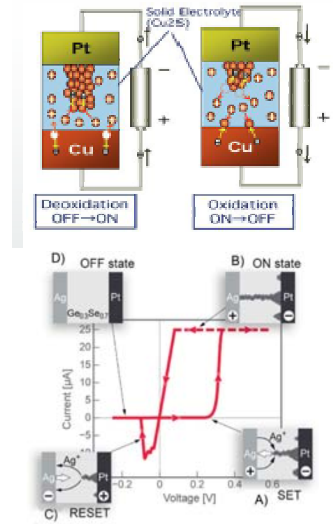
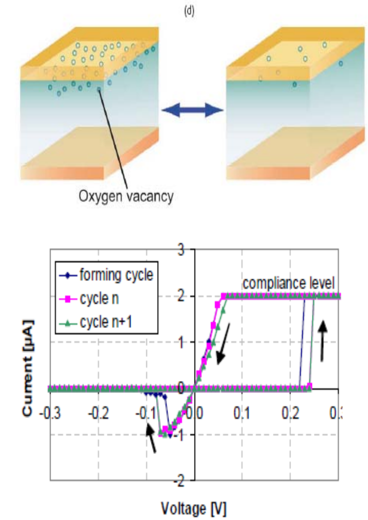
Applications:

- One time programmable memory for DRM.
- High capacity ReRAM with switching speed faster than NAND for 3D camera.
- Tunable resistor in analog logic for pattern recognition.

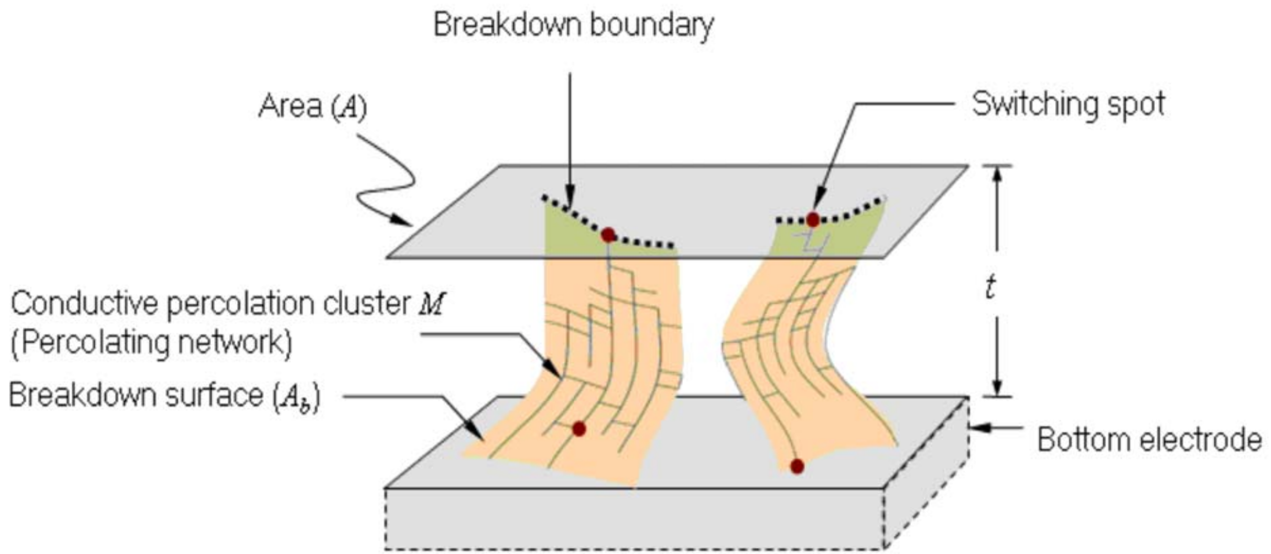
Required innovation:

- p^{+}–i–n type ReRAM materials
- Multi–level ReRAM materials

Switching mechanisms in ReRAMs

Fuse/Anti fuse memory switching	Electronic effect based switching	Metal ion motion based switching	Oxygen ion motion based switching
			
▪ Unipolar switching with diode ▪ Excellent retention	▪ Excellent uniformity ▪ Multilevel	▪ Fast P/E speed ▪ Low power ▪ Multilevel	▪ Fast P/E speed ▪ Excellent endurance ▪ Excellent statistical distribution ▪ Low power ▪ Multilevel
▪ Need electro forming ▪ Poor uniformity	▪ Poor retention ▪ Poor scalability	▪ Need low temperature process ▪ Poor retention/poor uniformity	▪ Poor retention

A switching mechanism in ReRAM

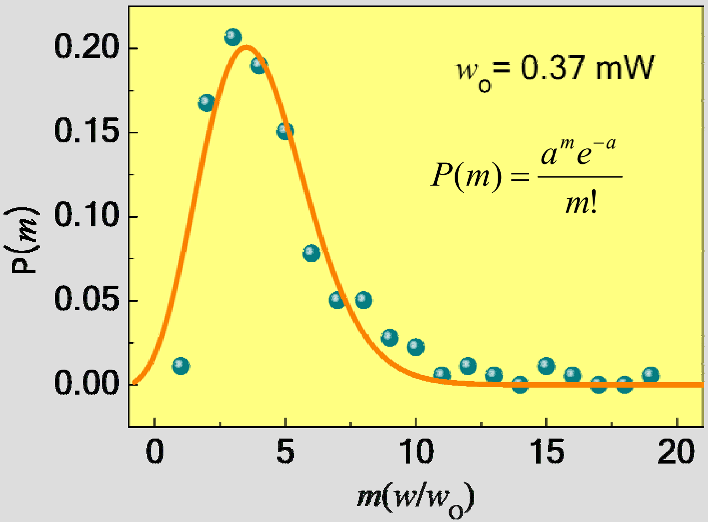


$$\text{Breakdown density}(\rho) = \frac{\text{total length of breakdown boundaries at the interface}}{\text{Interfacial area}} \quad [\text{cm/cm}^2]$$

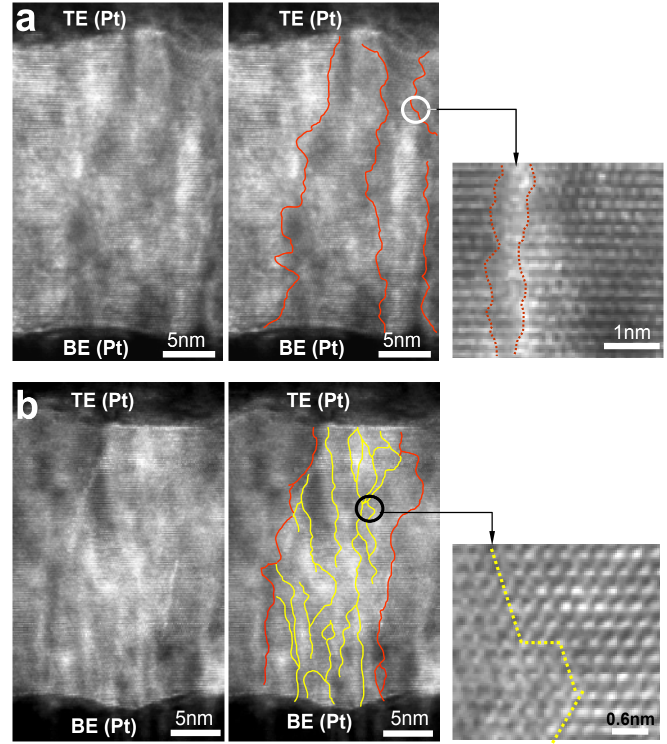
A percolation cluster model during resistance switching. The conducting cluster resides on the breakdown surface in the shape of a network. The main body of the cluster may not deform so much during switching. Instead, some spots in a percolating network may contribute to switching by connecting and disconnecting the cluster to the top and bottom electrodes. The cluster size is proportional to the electrode area in such a manner that

$M \propto A_b{}^d = (\rho A \alpha t)^d$

A switching mechanism in RRAM



Switching data distribution of NiO thin film. Four filaments are involved most frequently during reset (from "0" to "1") in the area of 30μm x 30 μm.



$P(m)$: **Probability density of either formation or breakage of chain of the conducting percolation cluster.**

n : **The total possible number of sites that can be involved in connecting clusters to the electrode.**

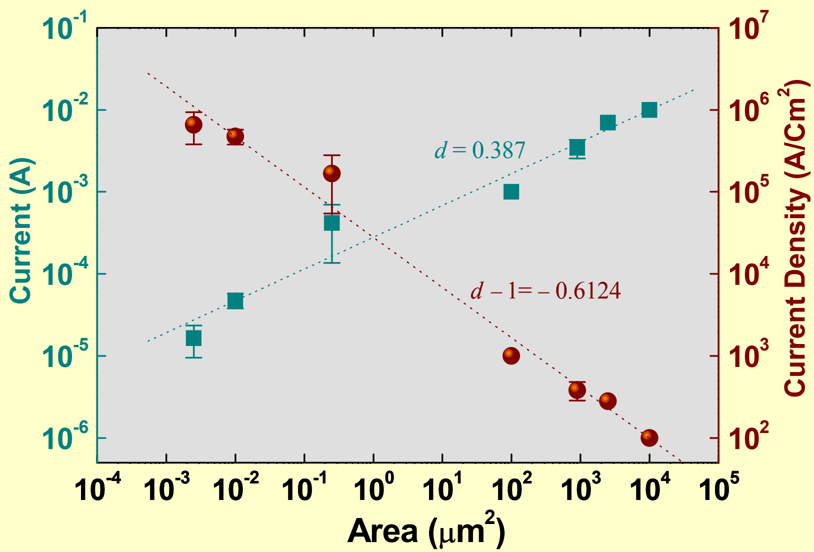
p : **Probability of connecting spot formation.**

m : **The number of success to form connecting spots in area A.**

s : **Site density in area A.** $a=np=sAp$

A switching mechanism in ReRAM

Fractals in ReRAM switching



Current versus electrode area at a conductive (reset) state.

$M \propto A_b^d = (\rho A \alpha t)^d$

***M*(*r*) ∝ *r*^{D}, where *M*(*r*) is the number of points in the sphere of radius *r* with fractal dimension *D* with *D* < 2.** *

$M(r) \propto A_b^{D/2}$

and it is assumed that

$m \propto \sqrt{M(r)}$,

then $m \propto A_b^{D/4} \propto A^{D/4}$.

Since $I \propto m \propto M \propto A^d$,

$\ln I \cong d \ln A +$ **constant**

$\ln J \cong (d-1) \ln A +$ **constant**

, where $d = D/4$.

Thus, $d < 0.5$

*T. Nakayama and K. Yakubo, Fractal concepts in condensed matter physics, (Springer series in solid-state sciences, 2003).

Research suggestions on ReRAM

- Business model and product concept for ReRAM can be created by evolution patterns.
- Chaos and complexity phenomena should be considered in ReRAM studies.
- Reconfigurable logic may be one of promising areas for ReRAM applications.
- Applications of oxide ReRAM materials can be expanded to transparent oxide electronics including transparent sensors.