

Reliability of micro and nanotechnology applications

Denis Koltsov

Stresa, Italy (25 April 2006)

Overview

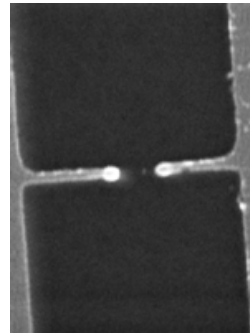
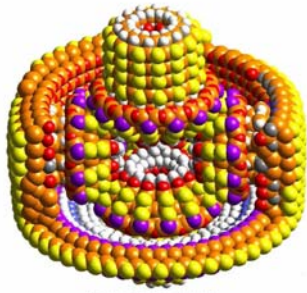
- MNT perception cycle
- Introduction to reliability
- Application of reliability theory to MNT
 - Top-down fabrication
 - Bottom-up assembly
- Failure of MNT devices with high redundancies

25 April 2006

Denis Koltsov

2

Micro and nano

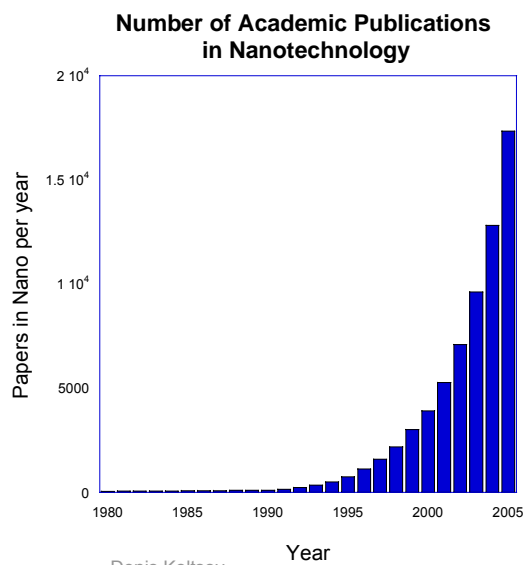


25 April 2006

Denis Koltsov

3

MNT academic publications

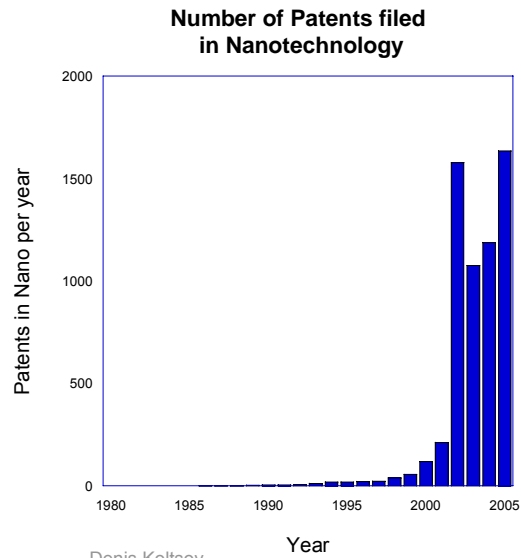


25 April 2006

Denis Koltsov

4

MNT intellectual property

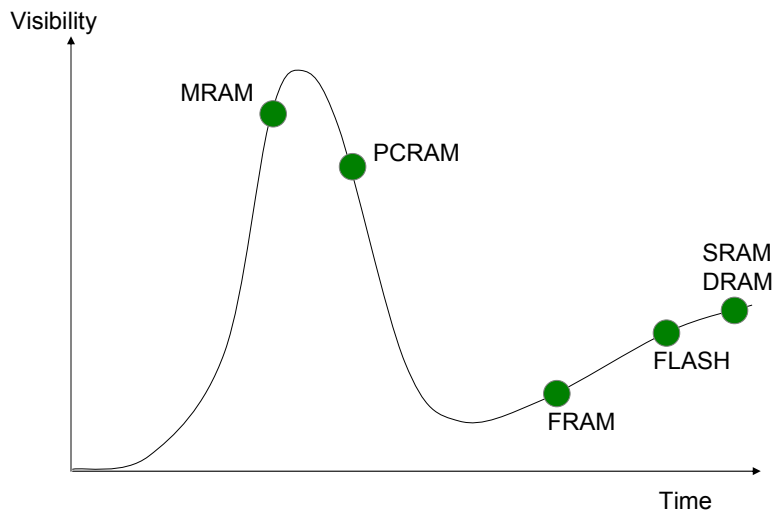


25 April 2006

Denis Koltsov

5

Technology development cycle



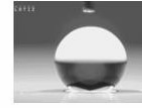
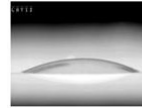
25 April 2006

Denis Koltsov

6

Some real world MNT applications

- Textiles
- Coatings
- Nanomaterials
- Electronics
- Data Storage
- Pharmaceuticals



Sandvik Nanoflex® - Sports
Designed for extremes
Sandvik Nanoflex® - Security & Safety
Designed for impact



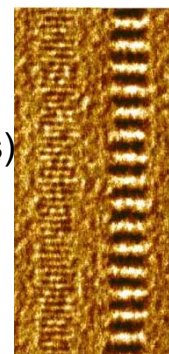
25 April 2006

Denis Koltsov

7

Commercial viability of MNT

- Miniaturisation brings
 - Downsizing of components
 - Faster operation rates (in some cases)
 - Cost
 - More elements (possibility of system redundancy)
- How reliable is this paradigm?



25 April 2006

Denis Koltsov

8

MNT device reliability issues

- Reliability issues in MEMS (as an example)

During Fabrication:

Breaks during release
Inadequate release
Stiction
Geometric variations
Residual Stress
Protuberances
Particles contamination

During Operation:

Stiction
Microwelding
Fatigue
Wear
Interfacial Delaminations
Electrical Overstress

Environmentally Induced:

Contamination
Vibration
Shock
Humidity
Ambient

General theory of reliability

- Define a failure (mortality) rate $\mu(x)$ as

$$\mu(t) = -\frac{dS(t)}{S(t) dt}$$

– Gompertz law

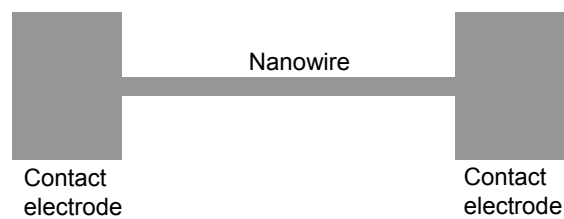
- Failure law

$$S(t) = S_0 \exp(-\mu t)$$

Where $S(t)$ is the reliability function

Conventional Top-down fabrication

- Deterministic fabrication methods such as lithography
 - Eg Nanowire (failure of one nanowire will cause the whole device to fail)



- We assume non-aging components

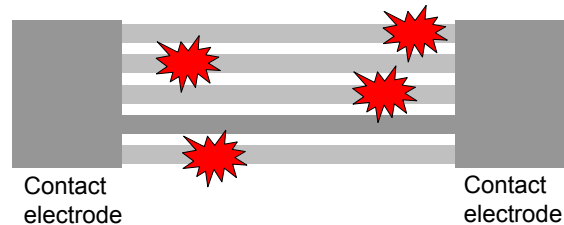
25 April 2006

Denis Koltsov

11

Building in redundancy

- Miniaturisation allows to build in redundancy in the system
 - Each element is non-aging
 - Each element has a finite failure probability



- Lessons from biology

25 April 2006

Denis Koltsov

12

Redundancy in the design

- Constant death rate system

=> Gompertz law $S(t) = S_0 \exp(-\mu t)$
 $\mu(t) = \text{const}$

Law describes well extrinsic death rate

Very applicable to Biology

Device redundancy in the system

=> Weibull law $\mu(t) = \lambda t^\alpha$

Related to age related deaths

Applicable to MNT devices

In reality

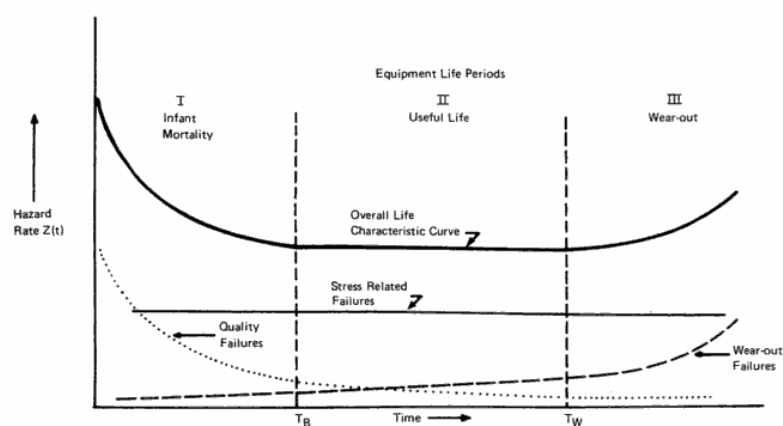


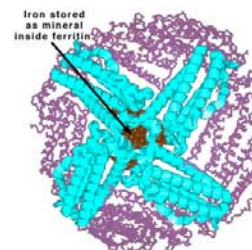
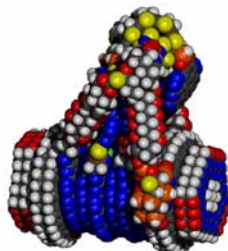
Figure 1.1 The bathtub curve. [From *Reliability Design Handbook (RDH-376)*, copyright 1976 by IIT Research Institute, RADC/RAC, Griffiss Air Force Base, N.Y.]

Top-down device with redundancy

- Redundancy introduces higher initial failure rate.
- Device increases in size
- Device is harder to fabricate
- Device history is important

Bottom-up approach to redundancy

- Solution to creating a very redundant system is to
 - Use self-assembly
 - Use biological samples or templates



Conclusions

- Reliability Theory is directly applicable
- Redundancy in the system:
 - Allows device to perform
 - The initial mortality rate is increased
 - Size of the device is increased
 - Device history
- Bottom-up approach
 - Reduces the cost of adding extra redundancy

The end

- simplest
- The survival of the ~~fitest~~