Design for Micro & Nano Manufacture (Patent – DfMM)

- Lowering the barriers to commercialisation for the next generation of micro and nano technology based products -

Accelerated Testing: from Microelectronics to MEMS

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1. Why accelerated testing for MEMS?

December 2003 - MEMS Industry Group - METRIC 2003 Report "Focus on Reliability", submitted to DARPA:

- Survey of 91 companies, 46 responded, 36 applicable;
- Conclusion: demonstration of reliability is required by customers;
- Accelerated testing is the main tool for demonstration;
- "Legitimate" accelerated tests must be created;
- Actions for MIG:
    - develop web-based reliability database,
    - sponsor / coordinate expert courses,
    - develop standards in the field;
    - communicate needs (fundamental research, equipment, methods, software) to suppliers (universities, research institutes, national laboratories, materials vendors, equipment manufacturers);
- Internal program of MIG: providing data, best practices and reliability resources to the MEMS community through the establishment of a website, a direct email campaign to inform membership of new reliability resources.

First conclusion:

“PATENT –DfMM” is well placed in the world competition on MEMS reliability, being focused on:

- web-based reliability database
- reliability resources
- expert courses
- standards

and having also an industrial group

1. Why accelerated testing for MEMS?

29-30 September 2004, Pittsburg (USA)

MEMS Industry Group - METRIC 2004

Report "MEMS Accelerated Lifetime Testing":

- In METRIC 2003, the ALT was among the most pertinent questions on MEMS;
- Since April 2004, a steering committee of 18 MEMS industry professionals has been working on isolating the most pertinent questions regarding ALT;
- In preparation for the ALT discussion, MIG has compiled a workbook that covers what is known already about ALT, and what needs to be known to address ALT in a manner that will speed commercialization;
- The idea was to concentrate the effort on the most important issue at this moment (ALT) in order to move forward;

MIG: more than 60 member companies (Honeywell, Intel, Texas Instruments, Samsung, Fairchild, etc.)

Second conclusion:

WP3 must move towards accelerated testing, as soon as possible!

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2. Basic principles of accelerated testing

Definition: The accelerated test is an aging deterioration of an item to induce normal failures by operating at stress levels much higher than would be expected in normal use.

Effect: The testing time is compressed and fruitful results are obtained much more quickly than in normal tests (at operational conditions).

Purpose:

- To identify design weaknesses (Accelerated Stress Testing – AST)
- To quantify reliability parameters (Accelerated Life Testing – ALT)

Accelerating factors: more frequent power cycling, higher vibration levels, high humidity, more severe temperature cycling, higher temperatures

2. Basic principles of accelerated testing

Caution:

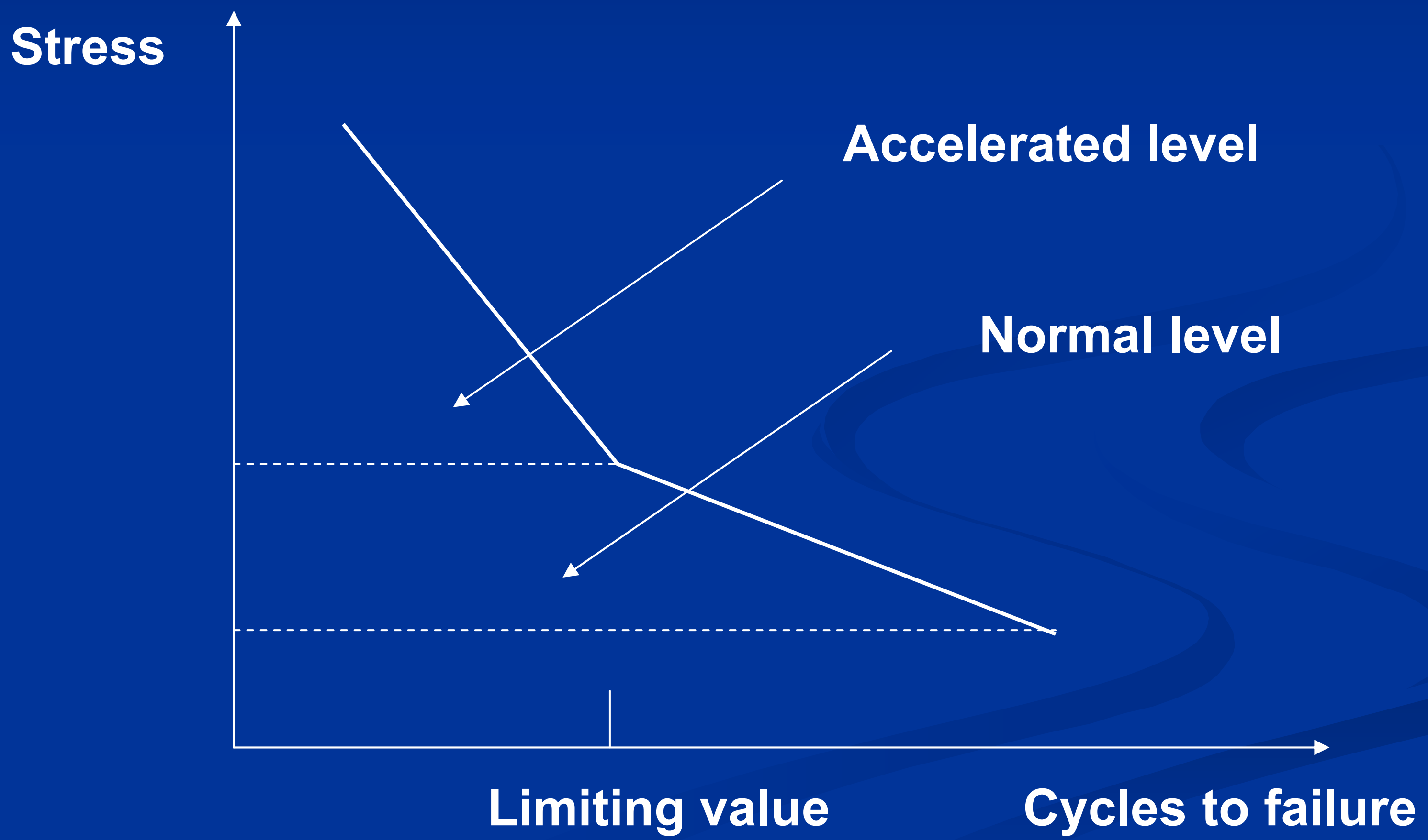
- The failure modes / mechanisms at high stress must be the same as at normal stress!

An accelerated tests is useful only if, under the accelerated conditions, the item passes through ALL the same states, in the approximately SAME order, as may expected in normal use, but in a much SHORTER period of time.

Failure analysis is essential for ALT:

- An understanding of the anticipated failure mode(s) / mechanism(s)
- A knowledge of the magnitutde of the acceleration of each failure mechanism, as a function of the accelerating stress (ALT models)

Change of the failure mechanism at higher stress level



ALT models:

- **Inverse Power Law:**

  Life (normal) / Life (acc) = (Acc stress / Normal stress)^n

- **Arrhenius Acceleration Model:**

  Life = A exp (Ea / kT)

- **Miner's Rule (Fatigue Damage):**

  Every part has a finite useful fatigue life and every cycle uses up to a small portion of that life. Failure is likely to occur when the summation of incremental damage from each load equals unity.

2. Basic principles of accelerated testing

Types of tests:

- Constant-stress testing: different samples, at different stress levels
- Step-stress testing: one sample, at progressive stress levels

New types of Accelerated Testing:

- Step Stress Profile Testing (used for analysis, not for predicting life)
- Progressive Stress Profile Testing (“ramp test”, stress level is continuously increased with time)
- Higly Accelerated Life Test - HALT (to identify design weakness and manufacturing process problems; mainly for systems)
- Higly Accelerated Stress Screens- HASS (to go to the “fundamental limits of the technology”; mainly for systems)
- Higly Accelerated Temperature and Humidity Stress Test - HAST (stronger than the “old” temperature/humidity test)

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1. Why accelerated testing for MEMS?
2. Basic principles of accelerated testing
3. Recent developments in accelerated testing for MEMS
4. Lessons learned from microelectronics
5. Conclusions

3. Recent developments in accelerated testing for MEMS

Failure modes of MEMS:

- **Early life failures (**process / yield related issues, unpredicted, difficult to manage and can consume many resources to solve; Examples: particle contamination, surface contamination stemming from electrochemistry, outgassing, wafer-to-wafer hermeticity failures originating from microcracks, delamination, electrostatic discharge etc.)

- **Intrinsic failures** (wear, creep, deformation, dielectrics charging, thin film formation, arcing, electromigration, oxidation and corrosion, long-term outgassing, etc.)

3. Recent developments in accelerated testing for MEMS

Failure modes of MEMS:

Top five failure modes (production) by device type

Actuators	Sensors	Integrated systems	Passive Elements
Stiction	Electric short / open	Temperature	Contamination
Wear	Leakage	Contamination	Package stress
Electric short / open	Package stress	Clogging	Electric short / open
Package stress	Contamination	Package stress	Crack propagation
Contamination	Crack propagation	Leakage	Deformation

3. Recent developments in accelerated testing for MEMS

Failure modes of MEMS:

Ability to accelerate

Most able to accelerate

- Electrical short/open
- Temperature
- Wear
- Crack propagation
- Package stress
- Leakage
- Creep
- Outgassing
- Passivation
- Stiction
- Delamination
- Charge accumulation
- Deformation
- Contamination
- Micro weld
- Surface modification
- Clogging

Least able to accelerate

3. Recent developments in accelerated testing for MEMS

- MIG recommends:
  - Collecting more data on accelerated tests needs and trends
  - Securing more university and corporate research funding
  - Evaluating and selecting different technical solutions

  - **Suggested actions for various failure modes:**
    - Stiction: to quantify the magnitude of the problem; an industry resource website
    - Surface contamination: more expensive tools are required to prevent it; independent laboratories for testing advanced forms of accelerated tests
    - Trapped charge: a better understanding of physics
    - Dielectric charge: no lifetime models till now; literature search is needed
    - Creep and deformation: macromodels are required

Third conclusion:

The subjects of WP3 joint research (e.g. collecting information on failure modes and material characterisation)are among the top issues of MEMS industry in this moment.

3. Recent developments in accelerated testing for MEMS

Field experience on failure modes of MEMS:

- **Texas Instruments: a 40 persons team (including 2 reliability engineers) developed a technique for predicting stiction through accelerated tests for DMD (Digital Micromirror Device)**
- **Sandia: derived a wear formula for a microengine where frequency and normal force were the accelerating factors, by operating a large number of parts for ling period of time to better understand the wear as a mechanism of failure.**
- **A small biomedical company: uses FMEA to rank failure modes; focused on customer satisfaction; no accelerated tests, because there are no available models for connecting data on tests with product lifetime.**

Fourth conclusion:

Accelerated test are very expensive and small companies are not able to use them. They need access to a database. WP3 could help these SMEs!

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4. Lessons learned from microelectronics

- MEMS industry must learn from Microelectronics industry, which offers a strong baseline of tools and controls development.
- Reliability problems are dramatically increased at MEMS, because:

  - the package must ensure not only the protection of the device, but also the connection with the environment;

  - to the well-known microelectronics issues , problems from mechanics, biology, chemistry, etc. are added;

  - MEMS industry is a young one, and information about techniques and processes are not yet available at large scale. Each company tries to obtain a breakthrough in the field…

Microelectronic devices vs. MEMS - 1

Electronics-only devices	MEMS
Design methodology focused on fast manufacturing cycles (accelerated testing).	New devices, without a history allowing to design accelerated testing.
Optimized standard processes, high yields.	The processes are not standardized.
The third dimension of the structures may be ignored.	The third dimension (the depth) of the structure cannot be ignored.

Microelectronic devices vs. MEMS - 2

Electronics-only devices	MEMS
Designers rarely know details about the manufacturing processes.	Designers must know details about the manufacturing processes (electronic / mechanical devices).
Package should separate the chip from the environment. Standardized cases.	Package should form a cheap but reliable interface between the active device and an often harsh, demanding environment.
Reliability problems are well-known.	New failure mechanisms (small distances between various functional elements, new phenomena).

4. Lessons learned from microelectronics

- In MEMS industry, the categories of reliability problems are basically the same as in Microelectronics (accelerated testing, failure modes, process reliability, etc.), only the particular solutions are (maybe) different
- The only way to build accelerated testing for MEMS is to follow the procedure used in Microelectronics.
- Hence, it is useful to know this procedure in order to orient the research toward this goal.
- In the following, the expertise of IMT-Bucharest in accelerated testing of microelectronic components is shown.

Accelerated testing at IMT-Bucharest

Components (discrete, IC):

- Small-series components manufactured at IMT-Bucharest
- High-series components manufactured by Romanian companies in semiconductors (Microelectronica, IPRS Baneasa)

Tests:

Accelerated Stress Testing - AST:

- stress testing for identifying design weaknesses;
- screening programs for various devices & applications;
- thermal ageing for components used in nuclear plants (in order to verify the functionning of a electronic module aged at 30 years)

Accelerated Life Testing - ALT:

- Constant-stress tests – quantitative determinations:
  - 3-4 samples of 20…50 items each, 1000 hours
- Step-stress tests – qualitative determinations:
  - 1 sample of 25…50 items, 10 steps, 4 hours at each step, bias + temperature

Accelerated testing at IMT-Bucharest

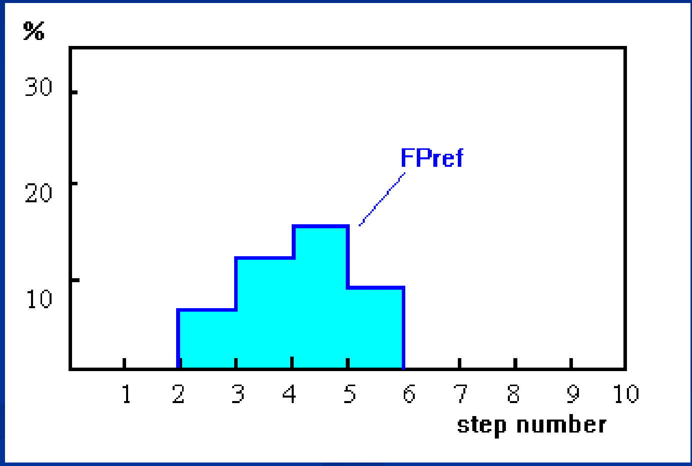
Screening programs for various applications

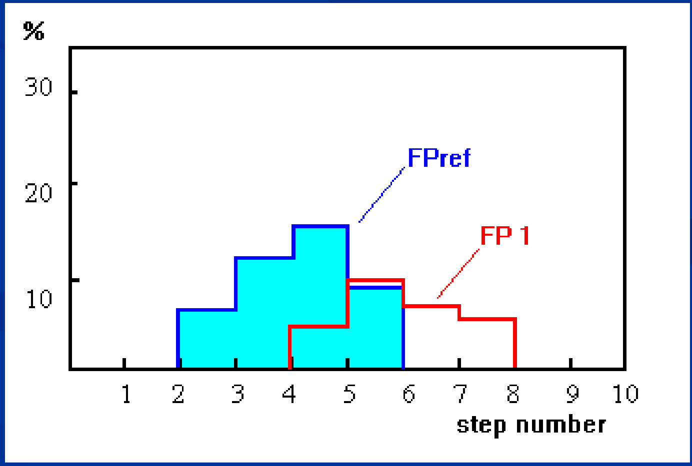
Tests	*P1*	*G*	*N*	*F*	*R*
Storage at high temp	72 h	72 h	48 h	48 h	48 h
Thermal cycling	5 cycles, 15 min / cycle	5 cycles, 15 min / cycle	5 cycles, 15 min / cycle	5 cycles, 15 min / cycle	5 cycles, 15 min / cycle
Constant acceleration	-	-	-	20.000 g 1 min	20.000 g 1 min
Hermeticity	-	6 atm, 4 h	6 atm, 4 h	6 atm, 4 h	6 atm, 4 h
Burn-in	-	-	48 h	96 h	168 h

4. Lessons learned from microelectronics

Step-stress test for qualitative determination:

- 1 sample (50 items)
- 10 steps (bias + temperature)
- The failures at each stress step are identified
- % at each step vs. step number = batch "fingerprint" (FP)
- Initially, FP is obtained for a reference batch (FPref), where λ (t), calculated by using constant-stress tests, is lower than a limiting value after a given time period.
- Then, for any subsequent batches, only FP is obtained with a short and cheap Step-stress test (FP1 in figure).
- By comparing FP1 with FPref, one may say if λ of this batch is bellow the limit.





(Paper in IEEE Trans.on Reliability, June 1995)

4. Lessons learned from microelectronics

ALT:

Contributions to statistical data processing: a generalized Arrhenius model (Bazu&Tazlauanu, Annual Reliability & Maintainability Symp., Orlando, Florida, USA, 1991)

$$t_m = t_{mo}(1+a_i \sum_{i=1}^{n} S_i^{b_i})\ exp(E_a/kF)$$

where t_{mo} is a constant, K – Boltzmann's constant, E_a – the activation energy, a_i, b_i – coefficients, S_i – stress factors (others than temperature and electrical bias) and F is given by:

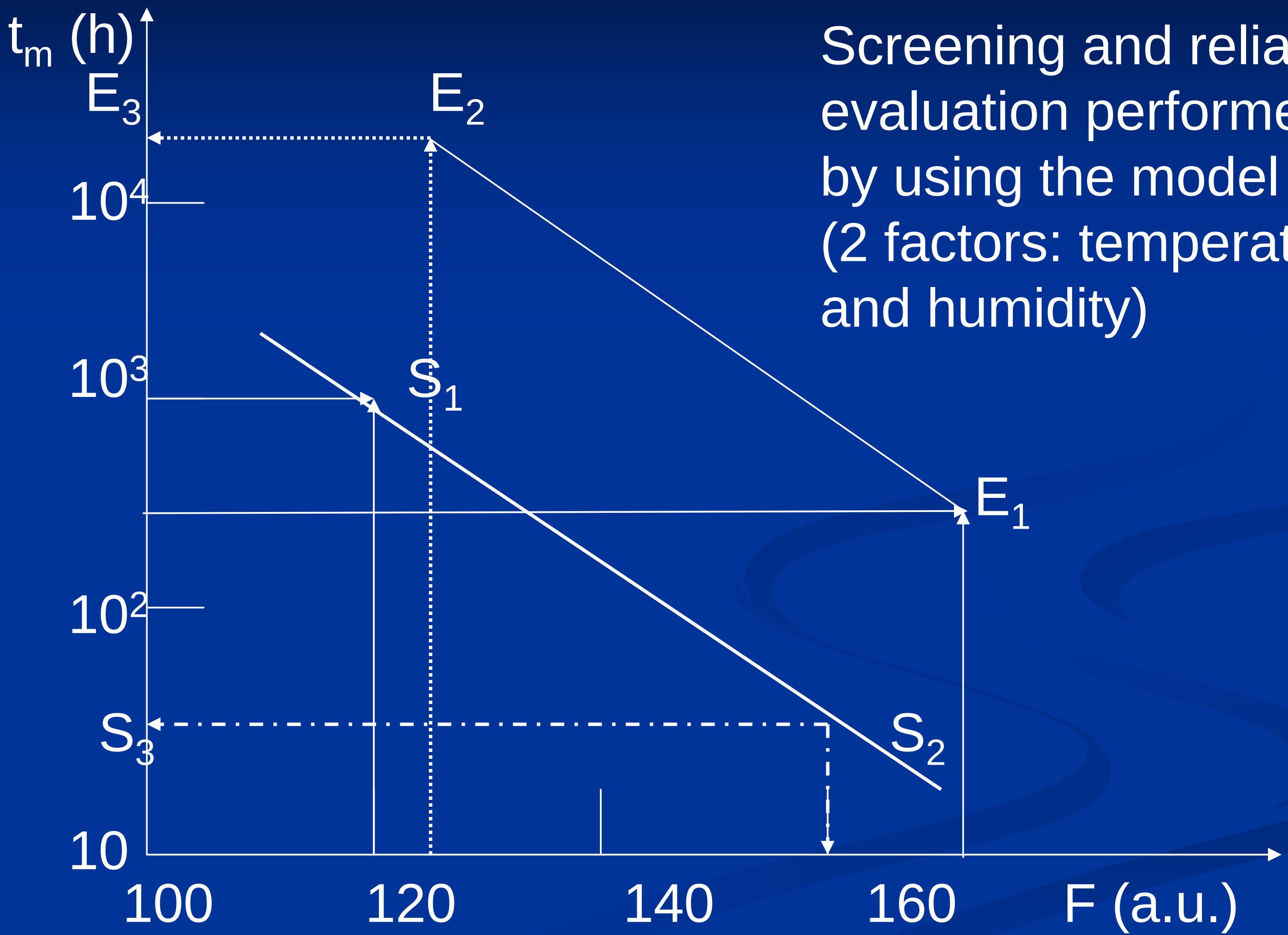
$$F = T_a + r_{th\ j\text{-}a}\ P_d + \sum_{i=1}^{n} c_i\ S_i^{d_i}$$

where T_a is the ambient temperature, $r_{th\ j\text{-}a}$ – the thermal resistance between junction and ambient, P_d – the dissipated power, c_i and d_i – coefficients. The coefficients a_i, b_i, c_i and d_i may be calculated form experimental data.

Other models are obtained as particulary cases:

- Arrhenius: S = 0
- Hakim & Reich: $b_1 = d_1 = 1$
- Lawson: $a_1 = 1$; $b_1 = 2$
- Peck: $a_1 = 1$; $b_1 = m$

4. Lessons learned from microelectronics



Screening and reliability evaluation performed by using the model (2 factors: temperature and humidity)

<u>An example</u>: ***Reliability analysis for the transistor 2N 3251 with constant-stress tests***

1. Design of the experiment: 7 samples (S1…S7) of 30 items each

Uce = 4.5 V	Uce= 9 V	Uce= 18 V	Uce= 40 V	Uce= 50 V	
			S7		Ta= 150 C
S1	S2	S3	S4	S5	Ta= 125 C
			S6		Ta= 80 C
Ic= 80 mA	Ic= 40 mA	Ic= 20 mA	Ic= 9 mA	Ic= 7.2 mA	

Reliability analysis for the transistor 2N 3251 (cont.)

2. Batch history (technological parameters)

3. Electrical characterisation

4. Accelerated tests (see table before)

5. Failure analysis: the main FMs are detected and statistical population for each FM are identified.

6. Three FMs: Inversion channel (characteristic for PNP transistor); EC shortcircuit (spikes-pipes) and purple plague (wire bonding)

7. Data processing for each FM: lognormal distribution with two parameters (tm and σ)

8. tm dependence on various parameters (V, T)

9. Ea calculation for each FM: 0.51 eV (channel), 0.42 eV (EC short), 0.92 eV (purple plague)

10. λ (t) curves for various conditions of bias / temperature.

CONTENTS

First four conclusions:

1. "PATENT –DfMM" is well placed in the world competition on MEMS reliability, being focused on: web-based reliability database, reliability resources, expert courses, standards and also having an industrial group
2. WP3 must move towards accelerated testing, as soon as possible!
3. The subjects of WP3 joint research (e.g. collecting information on failure modes and material characterisation) are among the top issues of MEMS industry in this moment.
4. Accelerated test are very expensive and small companies are not able to use them. They need access to a database. WP3 could help these SMEs!

.. Please, find the others!