Statistical approach for long-term predictions of 1550 nm laser diodes

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UMR 5818

Outline

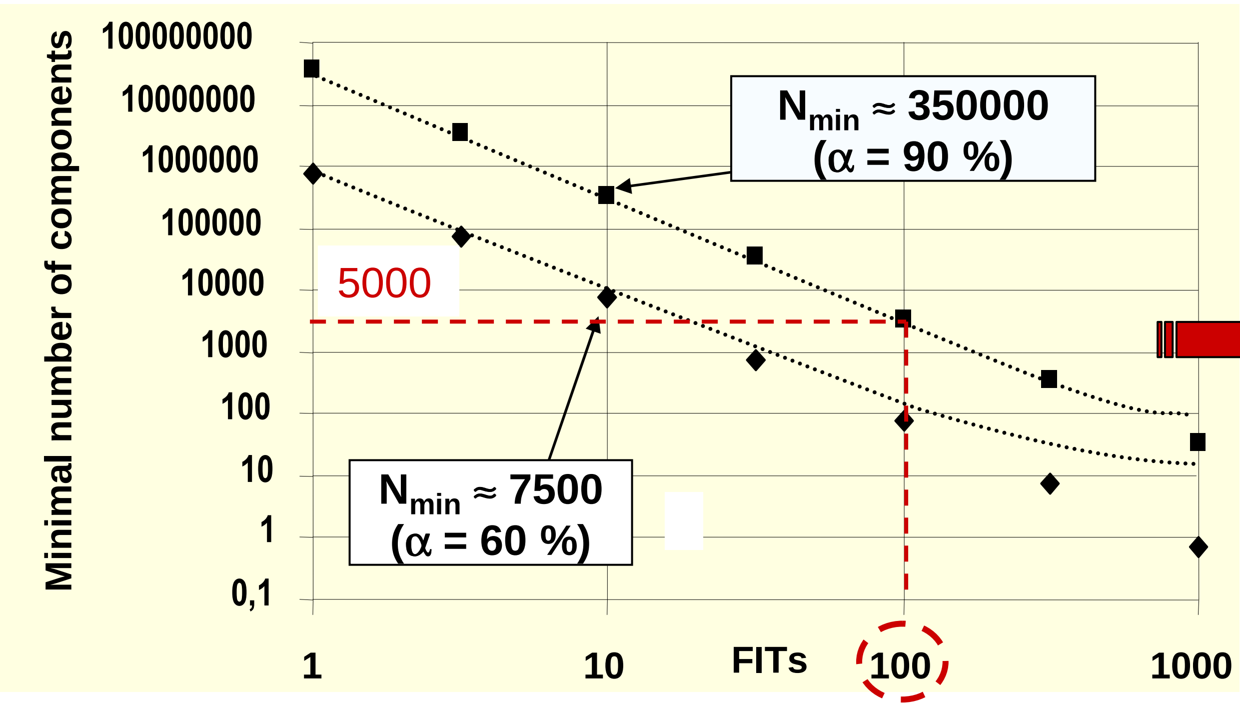
- Context and objectives
- Description of the Laser diode device
- Lifetime estimation
  - Degradation law extrapolation
  - Monte-Carlo simulation
- First time to failure extrapolation
- Conclusions and perspectives

CONTEXT

Emerging aspects for system reliability demonstration (1/5)

Example: N components with λ constant : exponential F(t) distribution
Activation energy : E_a = 0.6 eV
Test temperature : T = 125°C (400 K)
Duration of test : t_{test} = 1000 h
Acceleration factor : A_F = 350

α : Percentage of chances to obtain 50% of failures before t_{test} for $N>N_{min}$

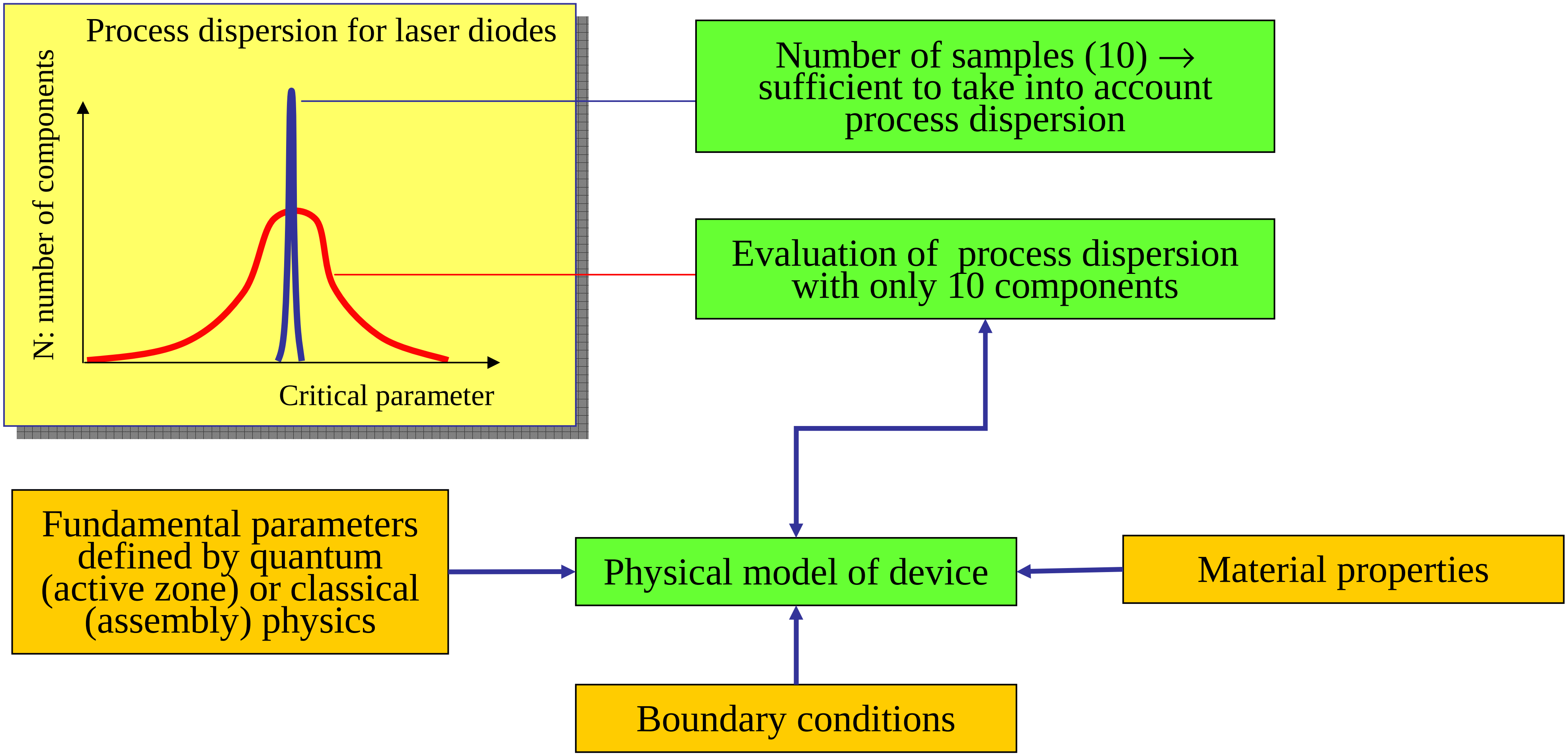


Unrealistic extraction of MTTF using qualification standards from low duration tests (< 5000h) and weak number of samples (< 20 components/batch)

⇒ Introduction of new test strategies or statistic approaches

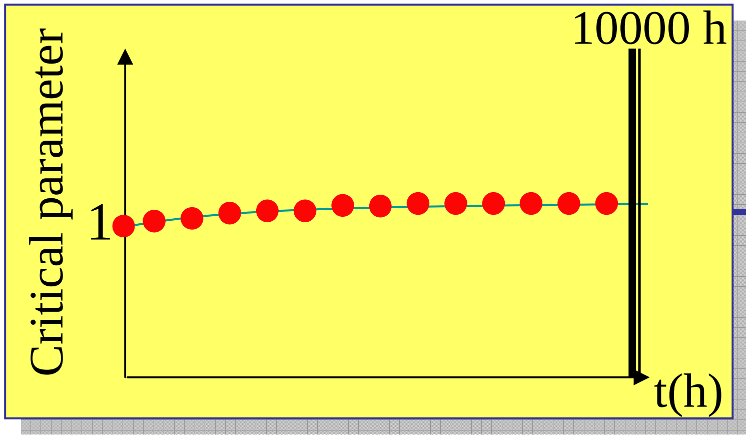
Context : Approaches for actual reliability estimation (2/5)

I - Number of samples < 10 → reduce the cost of qualification tests



Context : Approaches for actual reliability estimation (3/5)

II – Difficulty to measure the drift of electrical and optical parameters



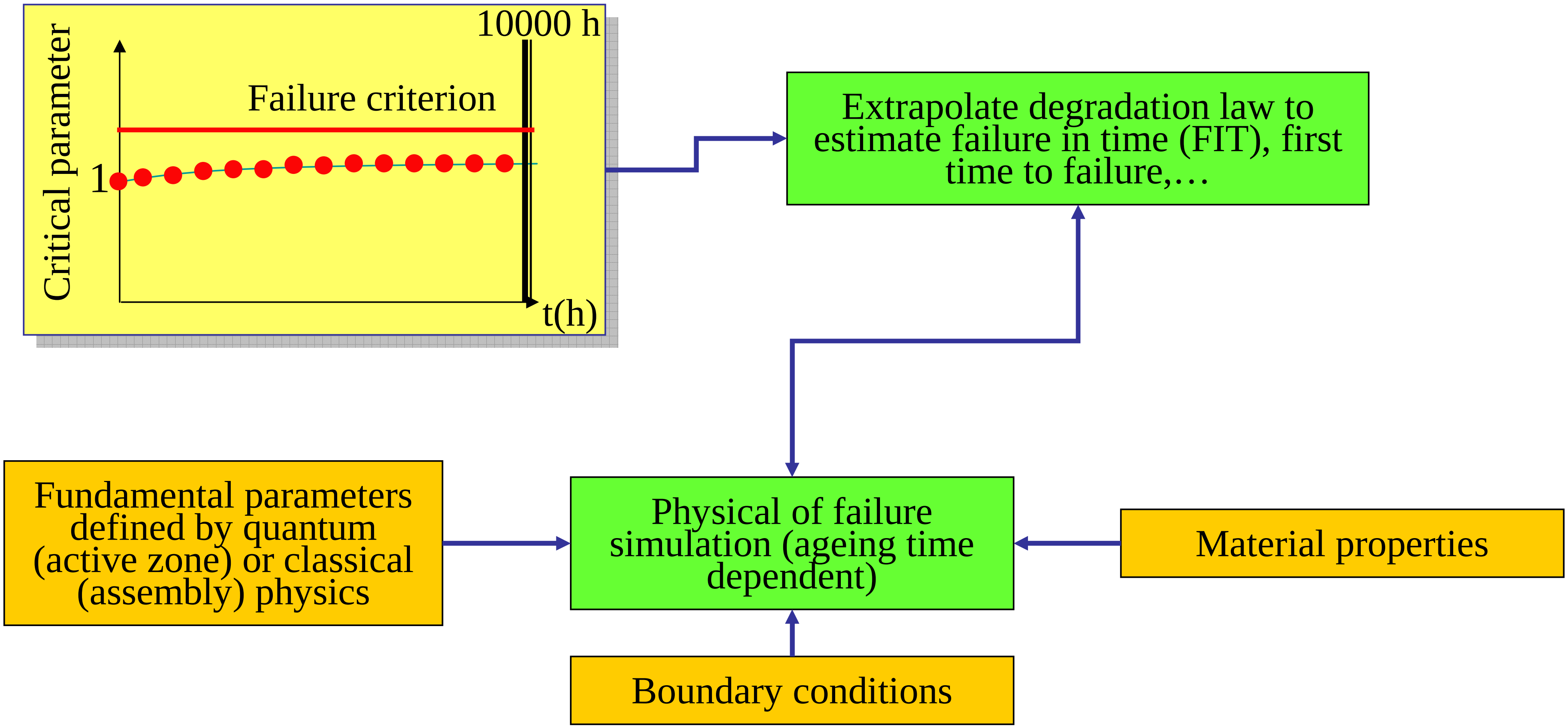
Reduction of the measurement error → best adapted instruments AND thermal management of the device

IXL facilities

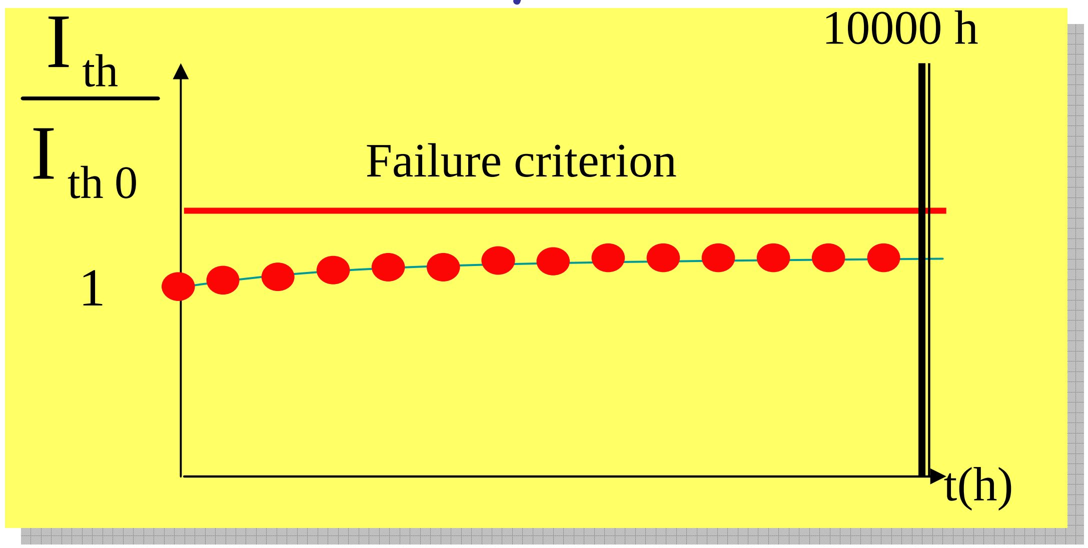
1/ DC electrical I(V)	Electrometer (Keithley 286) / 1 fA
2/ Spectral analyses	Spectrometer (TRIAX 320) / 26 pm / LEDs resolution
	HP 7000, HP 7094 & HP 11980 → 10 fm / Laser spect. linewidth Burleigh WA 1100 → 1 pm / Laser central wavelength
3/ Optical power	Integrated sphere (Labsphere) / 1 µW /Absolute measurement
4/ Thermal management	N_2 cryostat (Air liquid) / 0.1 K (77 – 473 K) – convection and conduction system ($\Delta T \leq 0{,}1$).

Context : Approaches for actual reliability estimation (4/5)

III – Failure criterion is not reached after qualification tests → stabilized technology



Context : Implementation scheme of academic laboratory work for reliability estimation



Non-destructive electro-optical measurement (initial characterization, process dispersion,…)

Physical analyses (quantum theory for accurate model) – Laboratory work

Extrapolation of the degradation laws

Elaboration of correlation laws – Laboratory work

Increase the number of samples by statistic simulation method (>1000)

Reliability estimation of laser diodes (lifetime distribution, physics of failure and impact of environmental stresses)

Objectives

Lifetime estimation and impact on system performances

Extrapolation of degradation laws in relation with physical parameters and failure mechanisms

Ex. : $\Delta X/X \approx at^m \exp(-E_a/kT)$

Increase the number of samples by statistic computations (> 1000)

Reliability estimation (t_{eol}, $\lambda(t)$, …)

SPIE 2004

Integration in system simulator

Impact on system performances

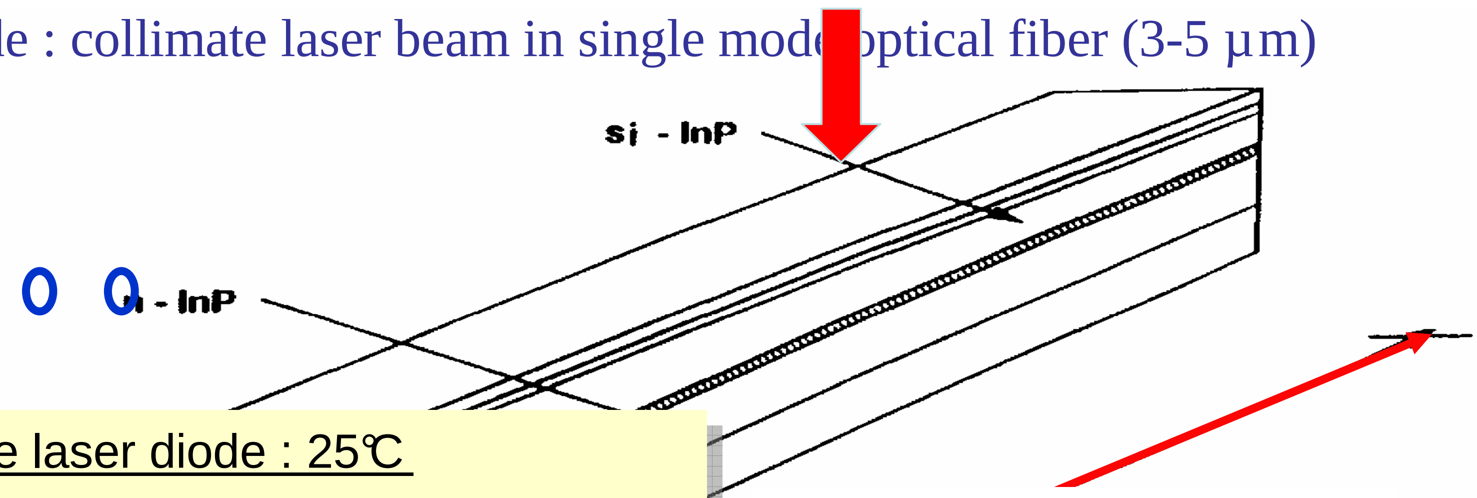
SPIE 2006

Description of the laser diode device

Single mode DFB Laser diode emitting at 1.55 µm

Active zone technology : InGaAsP/InP double buried heterostructure DBH

Passive waveguide : collimate laser beam in single mode optical fiber (3-5 µm)



Temperature of the laser diode : 25℃

Central wavelength λ_c : 1.55 µm
Operation current I_{op} : 150 mA
Operating temperature : 25℃
Spectral linewidth @ -3dB / P=10mW Δf : 2 M
Cavity length L : 500 µm
BH, MQW and single mode technology
Telecommunication applications
Direct current modulation
Data flow : 2.5 Gbit/s

Well-kno... n) inducing an increase of bias current

• Intrinsic defects located between blocking and active layers
... g dislocations)

... arges (ESD)

• Defects located in passive zone

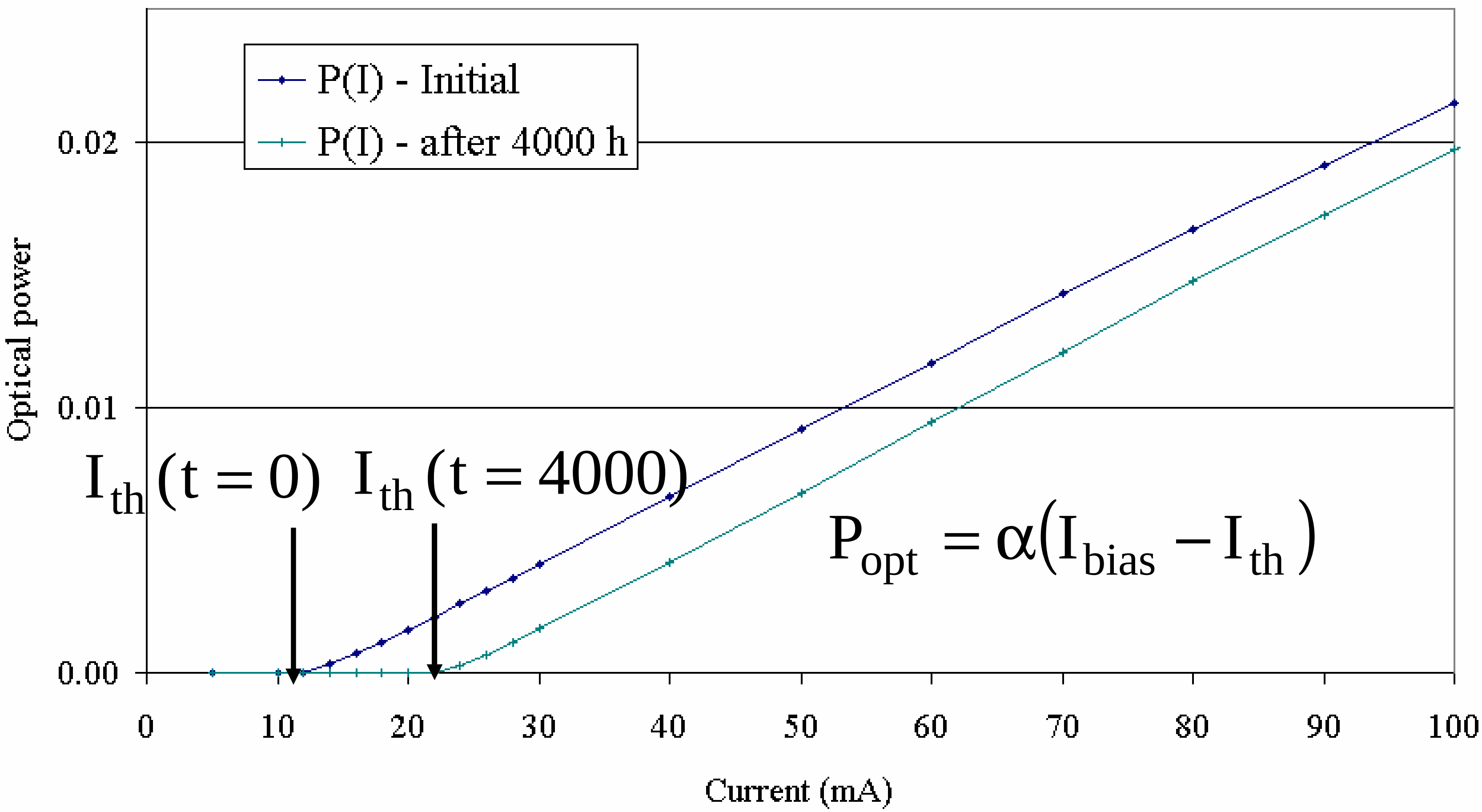
Description of the laser diode

Electro- optical experimental measurements

Typical electrical characteristic @ 300 K

Typical optical power versus current @ 300 K

Ageing test : 250 mA/100°C



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Lifetime estimation : Degradation law extrapolation

Test conditions and actual drift levels of laser diode for WDM applications :

- critical parameter : bias current $\rightarrow \Delta\lambda_C/\Delta I \approx 0.006$ nm/mA
- ageing test : active storage with constant optical power

  => 10 mW - 150 mA – 85°C

- failure criterion : 20 % of I_{bias} drift normalized by TELCORDIA 468 GR

  => NOT OBTAINED even after 10000 hours of ageing time

- Weak number of samples : **10 components only**

  => degradation law extrapolation : only 8% maximal of I_{bias} drift with typical equation :

$\mathbf{\Delta I_{op}/I_{op} = a\, t^m exp(-E_a/kT)}$ with 0<m<1 and activation energy : $E_a \sim 0{,}6$ eV

Lifetime estimation : Degradation law extrapolation

Experimental drift

Case 1	I_{bias} (3 to 10%)	I_{th} (0.05-2%) α (-0.5 to -4%)
Case 2	I_{bias} (0.05 to 1%)	I_{th} (0.05-1%) α (0%)

- I_{bias} : Bias current
- I_{th} : threshold current
- I_l : leakage current
- α : Optical efficiency

$$P_{opt} = \alpha(I_{bias} - I_{th})$$
$$\Rightarrow dP_{opt} = (I_{bias} - I_{th})d\alpha - \alpha dI_{th} + \alpha dI_{bias}$$

\+ If $dP_{opt} = 0$

Measurement conditions

$$dI_{bias} = -\frac{(I_{bias} - I_{th})}{\alpha} d\alpha + dI_{th}$$

Lifetime estimation

Degradation laws extrapolation
in relation with physical parameters
and failure mechanisms
(bias current for laser diode)

$\mathbf{\Delta I_{op}/I_{op}} = at^{m}\exp(-E_a/kT)$

Increase the number of samples by simulation method (>1000)

Reliability estimation
(teol, $\lambda(t)$, …)

Integration in system simulator

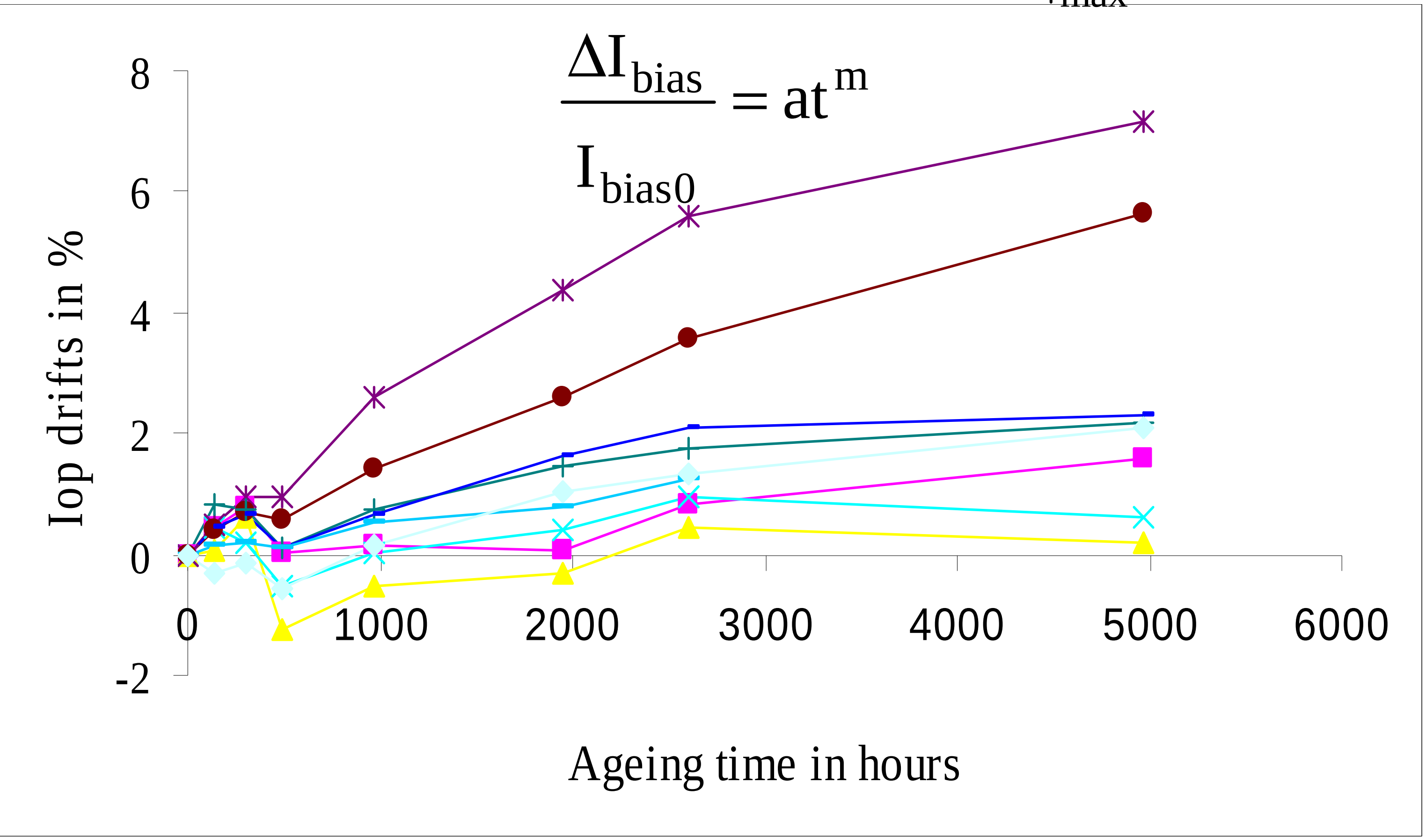
Impact of telecommunication network performances

Lifetime estimation : Degradation law extrapolation

Ageing test : active storage with constant optical power

=> 10 mW - 150 mA – 85°C

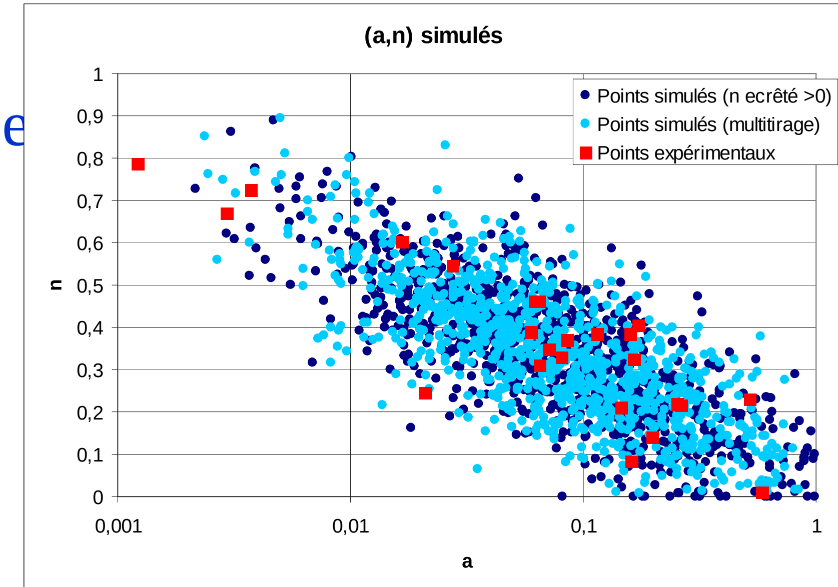
Failure criterion : $\left.\frac{\Delta I_{bias}}{I_{bias0}}\right|_{max} = 20\%$ is not reached

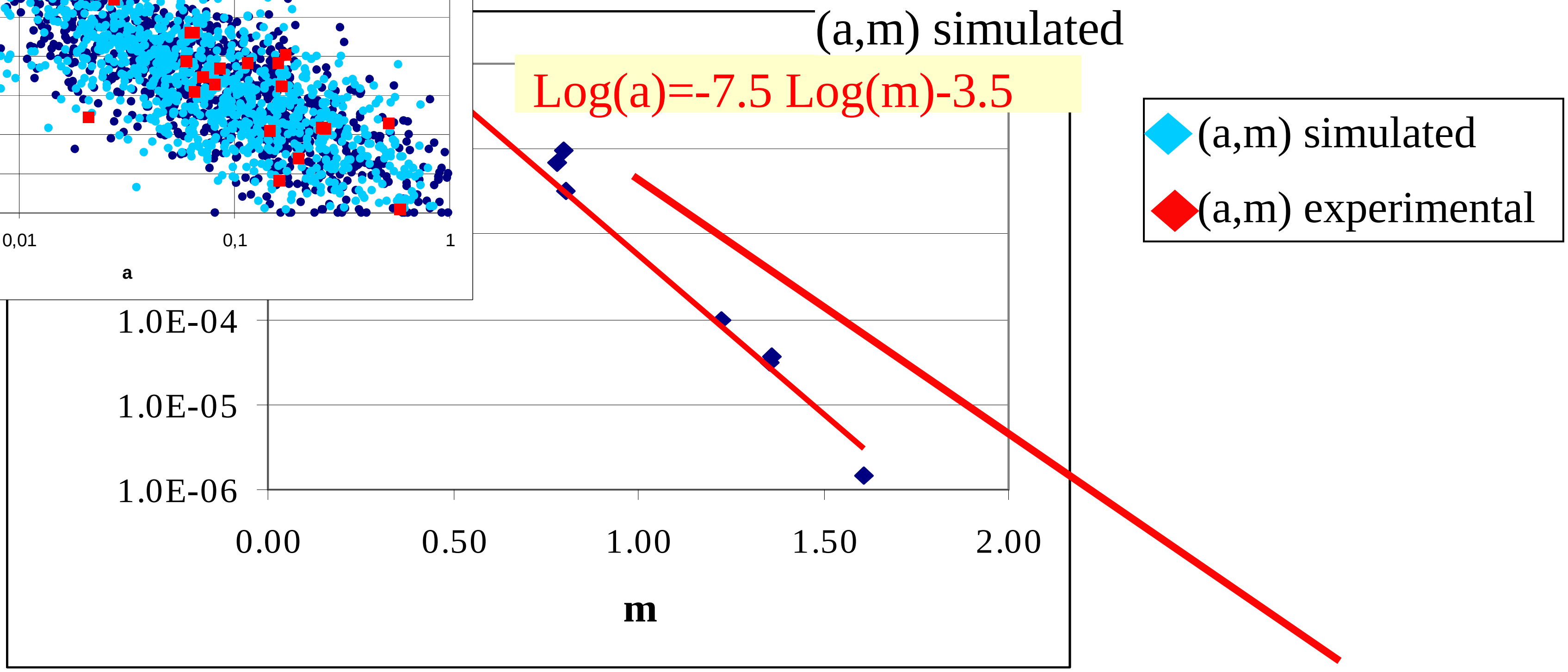


Lifetime estimation : Statistic computations

De… 10 laser diodes : a versus m experimental curve

…arly correlated : ln(a) = α ln(m) + β



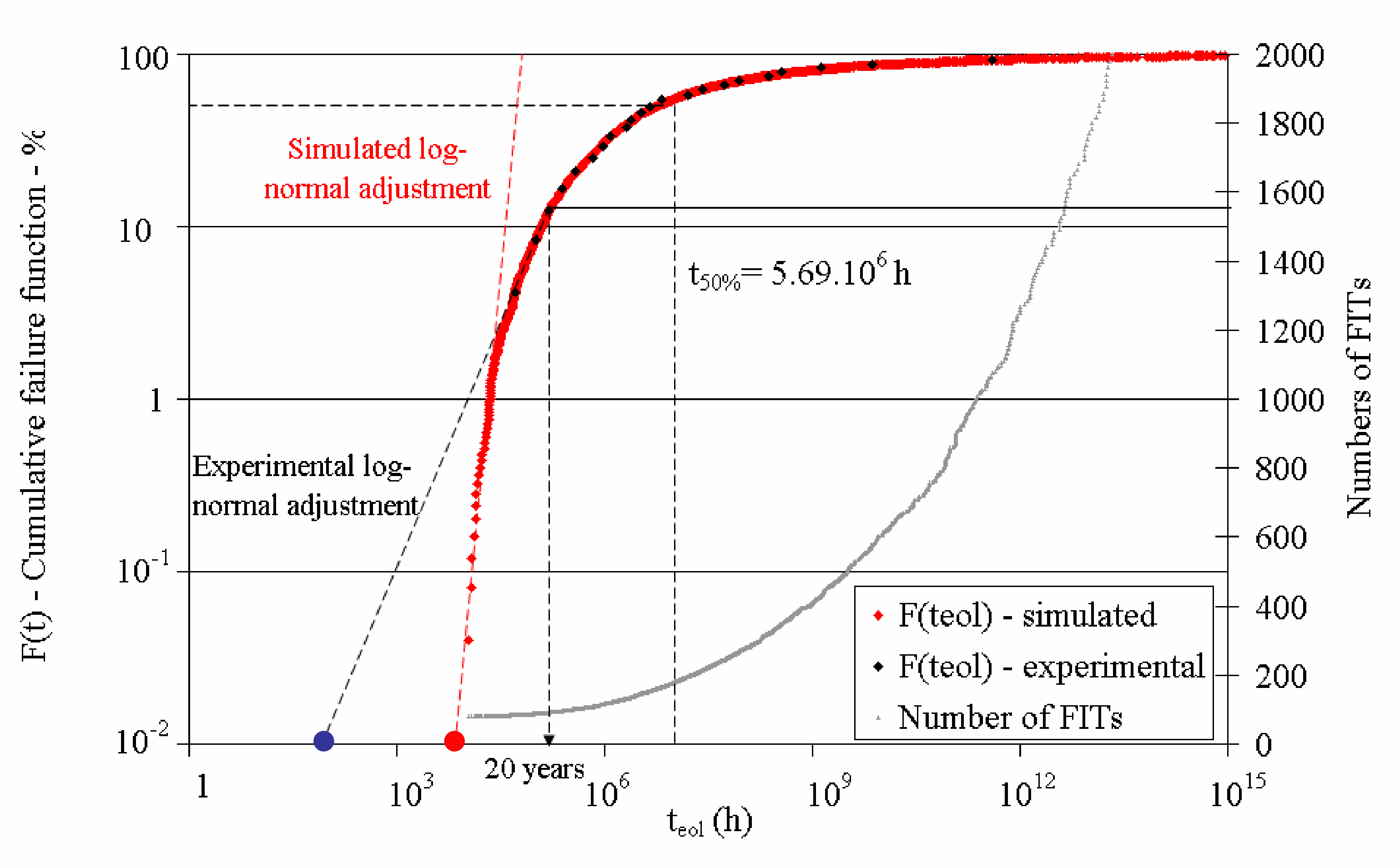


Increasing a number of samples using statistic simulation method (Monte-Carlo) → Log(a)=-7.5 Log(m)-3.5

First times to failure extrapolation

$$\lim_{t \to t_f} F(t) = 0$$

$$F(t) = 10^{-4} \approx 0$$



For failure criterion : 20% $\Delta I_{op}/I_{op}$

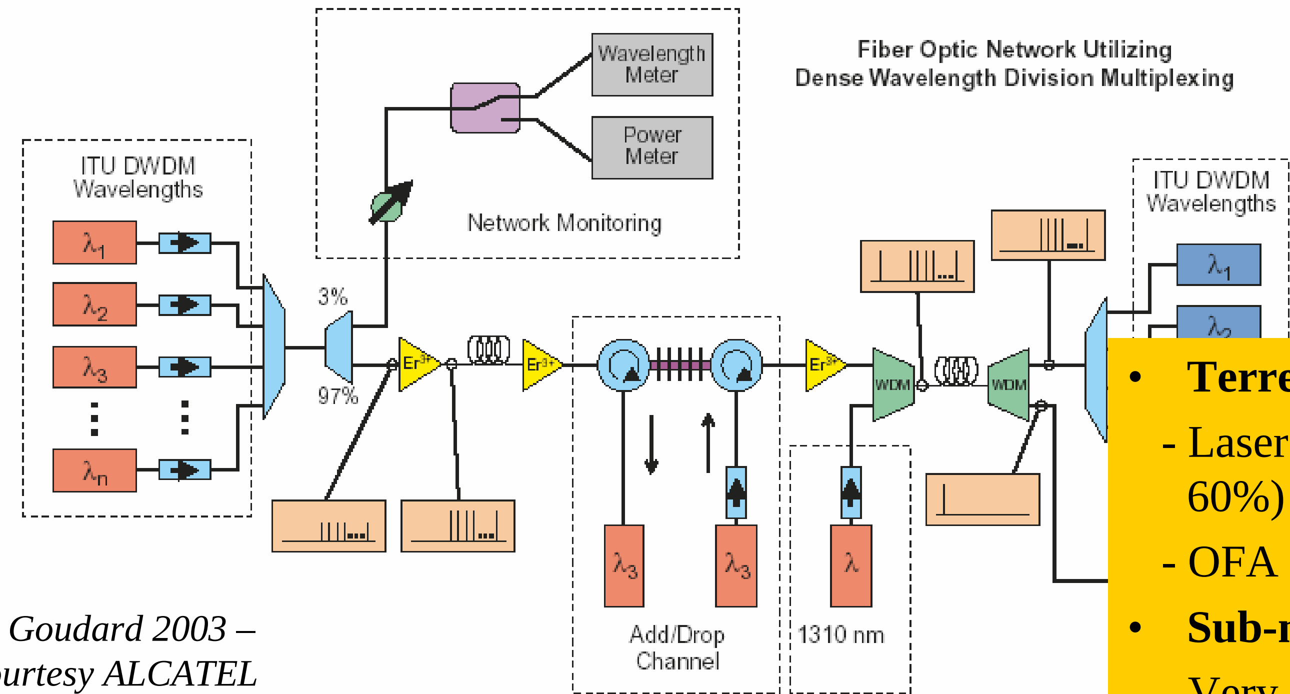
First times to failure estimation

≈100 FITs at 20 years

Conclusion and perspectives

- The relation between degradation laws and failure mechanisms have been given for DFB BH Laser diode
  - Increase of single mode laser diode DFB bias current
    - => drift of the central wavelength λ_C
- The strong interest of Monte-Carlo statistic methodology
  - estimation of the lifetime distribution and first times to failure
  - complementary tool of actual life-testing methods and physics of failure in the context of a reliability modeling approach

Emerging aspects for system reliability demonstration



JL Goudard 2003 – Courtesy ALCATEL

Telcordia-Bellcore-0468-CORE for active components :

- **Terrestrial networks** :
  - Lasers :100-500 FITs over 15 years (UCL 60%)
  - OFA : 500 à 1500 FITs
- **Sub-marine networks** :
  - Very difficult maintenability
  - Lasers : < 50 FITs over 25 years (UCL 95%)

$$\lambda_{system} = f\left(\lambda_{transmitter} . \lambda_{amplification} . \lambda_{fiber} . \lambda_{photoreceiver}\right)$$

Necessity of lifetime predictions using both failure mechanisms and distributions of experimental degradation kinetics for each element BUT ALSO INTEGRATE APPROACH OF SYSTEM SIMULATIONS

✓ **IMPLEMENTATION OF AN ORIGINAL APPROACH FOR RELIABILITY PREDICTIONS => Impact of specific failure criteria – Robustness evaluation of new devices (achromatic routing mux/demux for low-cost applications)**

✓ **IMPACT ANALYSIS OF INTRINSIC PARAMETERS DEGRADATION KINETICS OF THE LASER DIODE (assuming a power-law dependence) :**

- *Degradation of modulation bias current* :

=> Extinction of the eye diagram (> 40%), in correlation with the quality factor, on the degraded channel (reduction of almost 40%), after 25 years in operating conditions

- *Degradation of centre wavelength* :

=> Cross-talk generation between degraded channel and adjacent channel

=> Insulation increase from -80 dB in initial to -50 dB after 25 years in operating conditions

- Overestimation of center wavelength failure criterion regarding application conditions

=> For a maximal drift of 0,1 nm, the lifetime is basically reduced to 1 year. Or after 1 year, $Q \approx 8$ => BER > 10^{-15} !

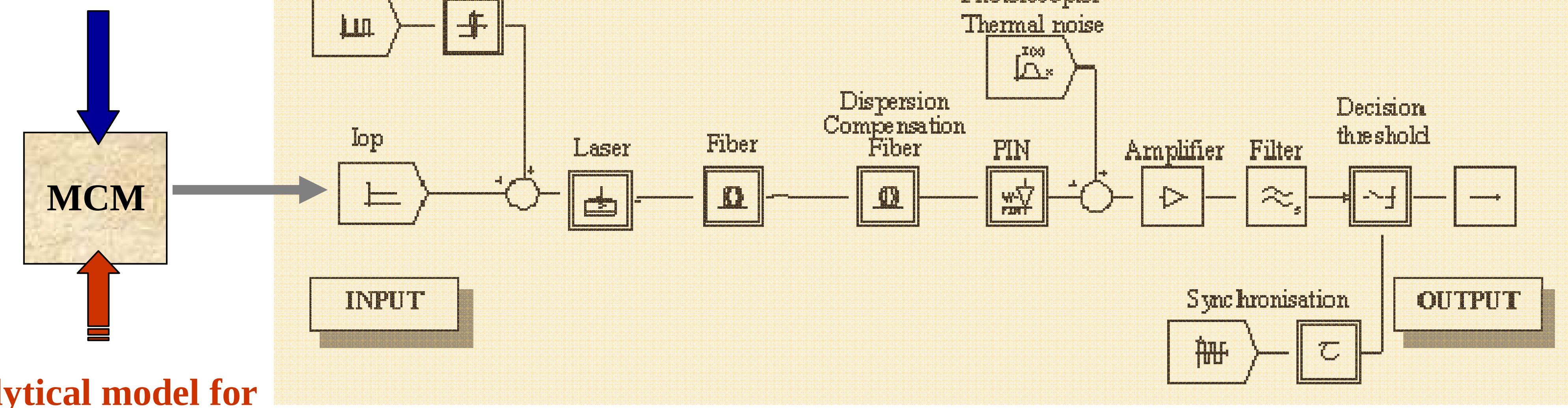
✓ **STRONG INTEREST TO STUDY THE IMPACT OF DEGRADATION KINETICS DISTRIBUTION OF MONITORED PARAMETERS**

IN PROGRESS ACTIVITIES : Implementation of Multi-Component Models (MCM) in system simulations

.3 µm FP Laser diodes

$\Delta I_{th} = f[N_{defects}(t), n_{th}(t)]$

SKK Lam, JAP 2004



Analytical model for 1.55 µm DFB Laser ?

In progress collaborations for this issue : *ENSIL (France), AVANEX-France (France), ALCATEL CIT (France), CEMD (University McMaster-Canada),*