FIELD RELIABILITY OF GaAs EMITTERS FOR FIBER OPTIC TELECOMMUNICATION SYSTEMS

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ABSTRACT

GaAs based emitters are widely used in telecommunication systems, and will be probably the core of short haul communications, even if a lot of doubts still exist on their reliability and the few available field results are not too optimistic.

For these reasons we decided to follow with a particular attention all the problems related to these devices, investigating reliability by means of accelerated tests and of an accurate survey of field troubles.

In this paper, we first of all report our field data, coming from more than five years experience, which show that "reasonable" results (in the range of 2000 FITs for LDs), can be obtained with commercially available devices; as a second step, failure analysis allows to localize failures,thus understanding the appropriate corrective actions to be taken.

For chip related failures, detailed examples are reported, highlighting the different failure mechanisms, that, when not related to specific process defects, are the same found during accelerated tests; we report also same examples of failures due to interconnections and packaging.

INTRODUCTION

The reliability of GaAs emitters used in fiberoptic telecommunication systems has always been of great concern due to the intrinsic weaknesses of these devices: in spite of the good figures obtined by accelerated test and of the efforts put by manufacturers in finding appropriate screening techniques, the few results reported on field reliability of lasers were quite worryng (up to $\lambda \cong 2 \cdot 10^4$ FITs) while better results were reported for LEDs [1].

From the very beginning of applications, we decided to follow with particular care the field returns, making use of our dynamic data base for system monitoring and surveillance and of the appropriate failure analysis techniques, which enable to understand failure mechanisms and to compare them with the ones experienced during accelerated life tests [2]. The overall results are described in this work which is, up to our knowledge, one of the first tentative to correlate real field data with failure modes and mechanisms.

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The devices taken into consideration are the emitters used in our "first window" systems as reported in Table I:

Device	LD	LD	LED	LED
Structure	DH	DH	DH-Burrus surface emitting	DH surface emitting
Confinement	Oxide-stipe	Proton bomb.	-	-
Emission wavelength (um)	0.88	0.84	0.86	0.90
Mounting	p-side up	p-side down	p-side down	p-side down
Coupling	tapered and spherical-ended fiber	spherical-ended fiber	lensing	spherical-ended fiber
Package	DIL-14	DIL-14	Coaxial	Coaxial
Monitor Diode	Si	Si	-	-

Table I - *Main thecnological characteristics of the analyzed devices.*

RESULTS

a) Field Data.

Our dynamic data base for system monitoring and surveillance enabled us to find field data in monthly reports.

Obtained data for lasers and LEDs are reported in Table II in term of the verified removal rate (RIT), taking into account all the removed devices and assuming, for semplicity, a constant failure in every year.

Year	Lasers	LEDs
1985	4280	-
1986	2670	540
1987	2140	470
1988	1920	830
1989	2450	780

Table II - *Removal rate (in RIT).*

As a second step, failure analysis (details are reported in the next paragraph) led us to localize the different kinds of degradation as follows:

-	Optical interconnections (connectors, splices)		30%
-	Packaging	Optical alignement	13%
		Electrical assembly (die attach, bonding,etc.)	14%
-	Chip		43%

b) Failure Analysis.

Failure modes are initially classified by means of electro-optical characteristics, then the real failure analysis is performed, mainly based on Electroluminescence and EBIC techniques that we found to be very effective for GaAs based emitters [2].
For LDs a great help comes from the availability of the internal photodiode, which allows to discriminate immediately between failures related to optical interconnections and alignement and those related to an actual decrease of optical power from the chip; in the latter case, mirror damage is the final failure cause, but different mechanisms can be identified :

- Formation of Dark Line Defects (DLDs) into the lasing stripe; Fig.1 shows an EBIC image with DLDs caused by growth of cristallographic defects in the active area. Dark Lines were found crowding in the stripe along preferential directions (90° and 45° angles with the stripe); as well known, [3-4], these defects come from epitaxial growth or from thermomechanical stress induced during process and aging, and act as non-radiative recombination centers, lowering the radiative efficiency along the active zone;during operating life, there is usually an external feedback circuit to keep the optical power constant, so that, when the radiative efficiency is too low, mirrors damage is induced, as reported in fig.1.

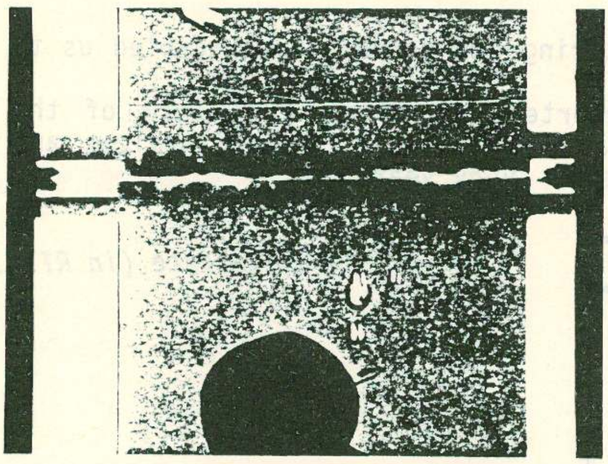

Fig.1 - *EBIC image of a degraded LD with DLDs in lasing stripe and mirror damage.*

We also found these kind of defects casually induced by mechanical scratches on the gold metallization, probably at the time of cleaving or SiO_2 sputtered coating (Fig.2), [5]; in our case, scratches also caused formation of dark regions, away from the laser stripe.

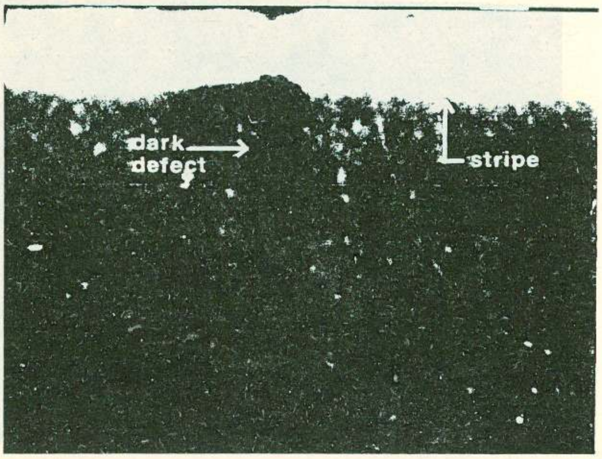

Fig.2 - *Superimposition of SEM and EBIC images showing scratch induced dark regions across the stripe.*

- Mirror damage only; from our experience, this effect is of particular concern during system manufacturing and test, when high current pulses can erroneously be applied causing destructive power densities at the mirrors; in field operation we were able to point out this phenomenon in defective devices only: fig.3 shows an example of mirrors damaging deeply propagating from both facets inside the chip, whose metallization is uncompletely defined at the end of the stripe, probably leading to bad thermal dissipation and overheating of the mirrors; this fact can give rise to a positive feedback effect, [6], which finally causes mirrors catastrophic degradation, with propagation of defects inside the active area.

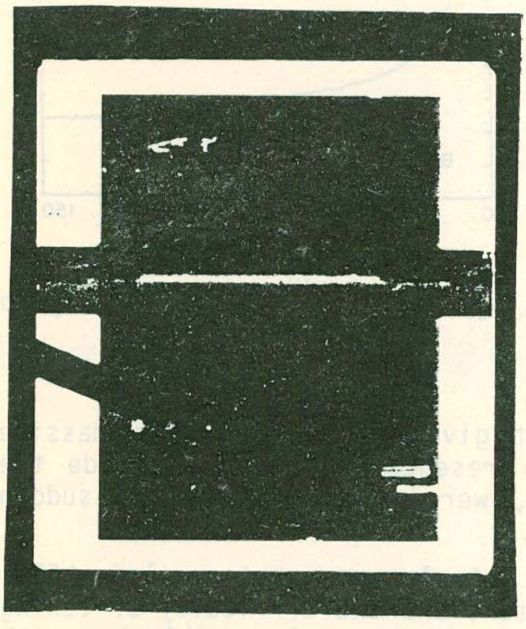

Fig.3 - *Mirrors damaging by thermal runaway of a LD (EBIC image).*

Regarding die attach-related failures, Fig.4 reports an example (not tipical!) of massive gold denditric growth: the EBIC image allows to understand that some parts of dendrites form Shottky contacts with the chip, justifying the irregular current-power and current-voltage characteristics shown in Fig.5: dendritic contacts behave like a parassitic diode which cause a sudden lowering of output power.

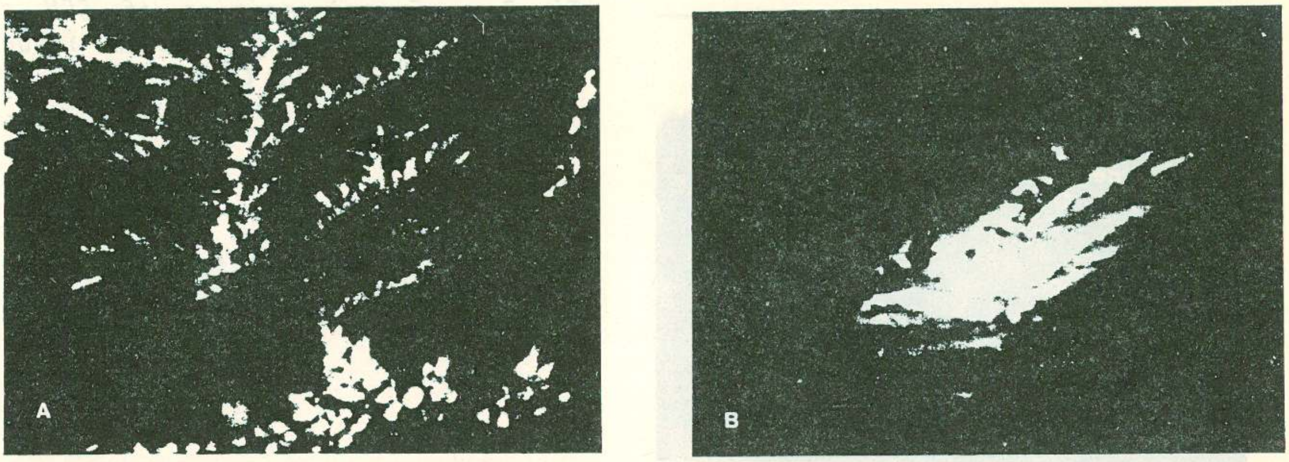

Fig.4 - a) SEM image of a gold denditric growth on the sidewalls of the chip.
b) EBIC image of the same denditric growth which form Shottcky conctact.

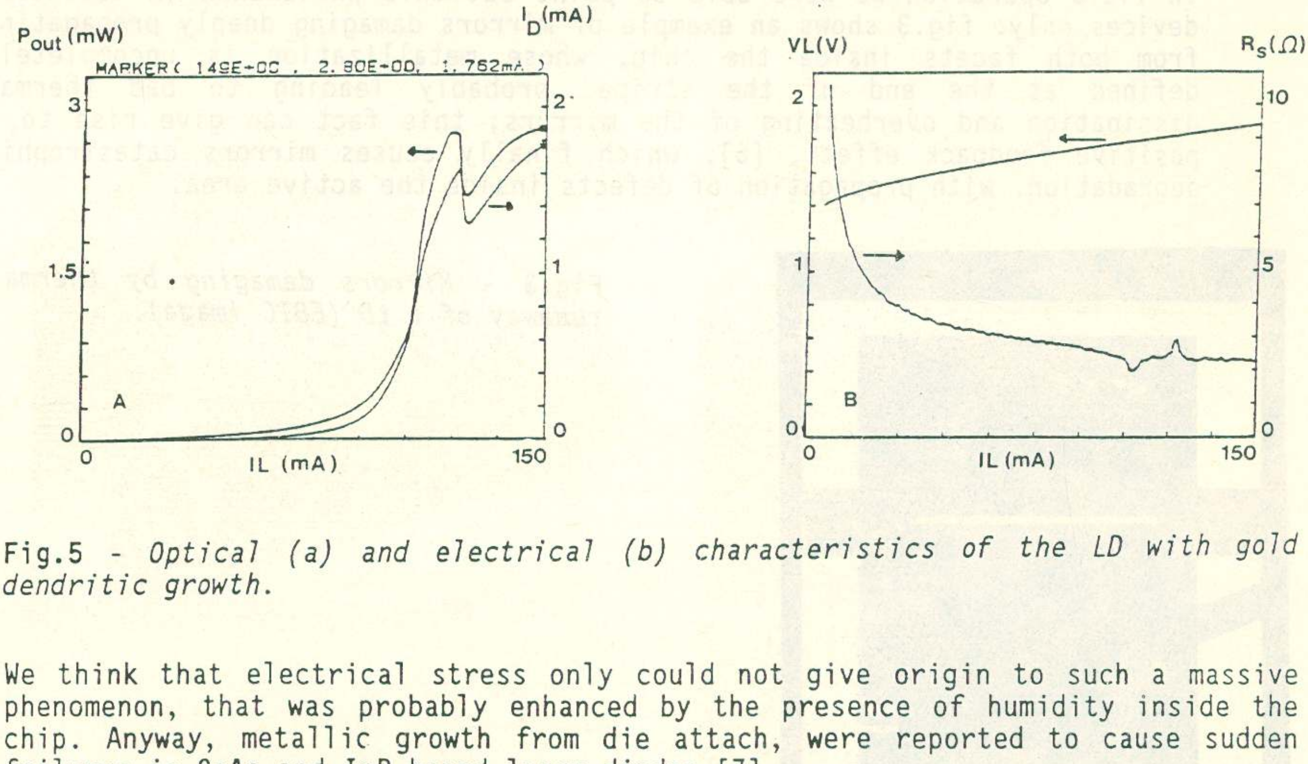

Fig.5 - *Optical (a) and electrical (b) characteristics of the LD with gold dendritic growth.*

We think that electrical stress only could not give origin to such a massive phenomenon, that was probably enhanced by the presence of humidity inside the chip. Anyway, metallic growth from die attach, were reported to cause sudden failures in GaAs and InP based laser diodes [7].

In spite of their simpler structure, it is not always easy to analyze LEDs: the lack of a double access to emission measurement and the difficulty of taking EBIC images of the devices mounted p-side down (that's indeed possible but with triky handling of the chip) limits the practical techniques to Electroluminescence and SEM microscopy.
Fig.6 shows the EL image from the top of a LED with heavy power reduction: dark structures, comparable with the ones obtained in LDs, are clearly visible inside the circular active zone, lowering radiative efficiency.

This effect, that was attribuited to dislocations growth initially originated from dopant diffusion at p-contact [8], was observed in 75% of field failures.

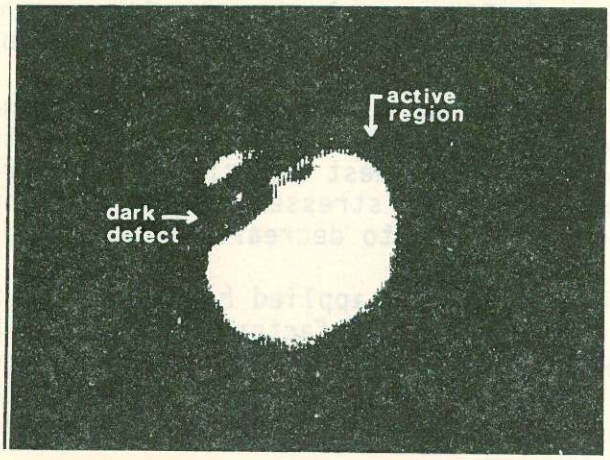

Fig.6 - *EL of a surface emitting LED with DLD in the active region.*

Another phenomenon highligthing the role of die attach is reported in Fig.7, where the bad thermal dissipation due to uncomplete die attach led to substantial degradation of ohmic contact and to the breakage of the coupling lens.

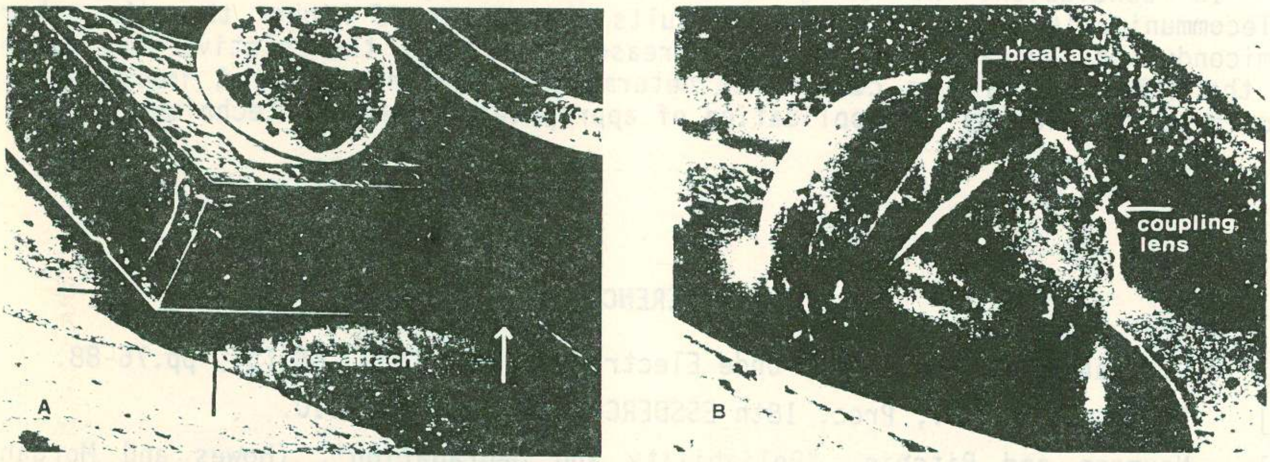

Fig.7 - *SEM images of a degraded LED showing:*
a) uncomplete die-attach;
b) breakage of the coupling lens;
c) contact degradation due to overheating.

DISCUSSIONS AND CONCLUSIONS

Combining together field data and failure analysis results, some conclusions on field reliability of commercially available GaAs emitters can be drawn:

- more than 40% of the failures are ascribed to optical interconnections and alignement; this problem is generally understimated, as people prefer to focus on active chips, that are considered the weakest parts; however more care in qualifying modules against thermomechanical stresses and in training people for installation and maintenance should help to decrease the nimber of failures.
- the other failures are in general accelerated by the applied bias, even if a subdivision can be found between those coming from manufactoring defects and the ones due to pure aging; all the failures related to die-attach and bonding are of the former type and can probably be eliminated by appropriate screenings, while 75-80% of chip failures are similar to those experienced during accelerated tests.
- a final summary of the failure causes can be as follows:

Mechanical stresses/handling	43%
Manufactoring defects	23%
Aging	34%

In conclusion, we analyzed field reliability of GaAs emitters for telecommunication systems, finding results that, even if higher than the other semiconductor devices, are still in a reasonable range; the relative importance of the different failure causes was determined, pointing out that improvements should be expected by the application of appropriate screening techniques.

REFERENCES

[1] P.Durand and F.Gobin, "L'Onde Electrique", May 1988, 68 (3), pp.76-88.

[2] F.Fantini et al., Proc. 18th ESSDERC 1987, pp.1007-1110.

[3] Neumann and Ritchie, "Reliability and Degradation", (Howes and Morgan ed.), p.301, 1981.

[4] B.W.Hakki and F.R.Nash, Journ. of Appl. Phys., 1974, 45 (9), p.3907.

[5] S.Todoroki et al., IEEE/IRPS, 1983, pp.160-166.

[6] C.H.Henry et al., Journ. of Appl. Phys., 50 (5), pp.3721-3732, 1979.

[7] K.Mitzuishi, Journ. of Appl. Phys., 55 (2), pp.289-295, 1984.

[8] A.Antolini and A.Piccirillo, CSELT Tech. Reports, Vol.X, No.4, pp.297-305, 1982.