Identification of Process/Design Issues during 0.18µm Technology Qualification for Space Application

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Abstract

Optical techniques (light emission and laser stimulation techniques) are routinely used to evaluate defects on specific component for space applications. Just one anomaly on one component could have catastrophic consequences on satellites. We must analyse any kind of fault of the device whatever the origin of thus fault is. It can be design, design-process, process or end user related…
At the early stage of an analysis, choosing the right technique is an increasingly complex task. In some cases, one technique may bring value but not the others. Using a 180nm test structure device, we will present results showing the complementarity of Emission Microscopy (EMMI), Time-Resolved Emission (TRE) and Dynamic Laser Stimulation (DLS) in order to help debug engineers to choose the right approach. This complementarity gives us ability to strengthen hypothesises before any kind of physical analysis.

1 Introduction

IC defect localization is often conducted with light emission or laser stimulation techniques. With technology for space application shrinks, higher frequency and increasing integration trends, failure analysis is getting more and more challenging and time consuming. Static and dynamic optical techniques play a key role in fault isolation but they have to continually improve to catch ever fainter faults. At the beginning of many analyses, it is difficult to choose the right fault isolation techniques between Static Laser Stimulation (e.g. OBIRCH [1]) or Dynamic Laser Stimulation (DLS), static light emission, and dynamic light emission. Generally speaking static setups is easier to implement than dynamic ones. Nevertheless, defect localization performed with static tools can produce valuable information but can also induce wrong hypothesis. Probing techniques such as Time-Resolved Emission (TRE) can complete other analysis or directly pinpoint a physical defect. Applying all the techniques is not relevant, time consuming and give a lot of useless data that can disturb the analysis. On the other hand, technique combination can collect complementary information about the defect and can generate the right localization and help to understand the failure mechanism. At the end, it improves and facilitates IC analysis.
Unfortunately, tool choices and combination of them is done according to a wide number of parameter. In this paper, we will not describe a full methodology, but indeed focus on different cases studies that underline some techniques combination.
We have based our work on the complementarity of Static Emission, Static and Dynamic Laser Stimulation and Time Resolved Emission.
We will present results that highlight the complementarity of techniques. Dynamic behaviour of test structure was studied giving us tiny defect localization and effects, timing delay measurements and timing gate sensitivity that could open a wide range of applications.
After a review of dynamic optical techniques used to perform experiments, as we described previously, we will present their implementation at CNES, the interest to have different techniques on the same system, and the modifications provided on the system. Finally the results obtained on 0.18 µm test vehicle.

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2 Dynamic techniques

2.1 Dynamic Laser Stimulation

Static Laser Stimulation (e.g. OBIRCH [1], TIVA [2], LIVA [3]...) and Dynamic Laser Stimulation (e.g. RIL [4], SDL [5], LADA [6]...) are important techniques for IC debug, IC isolation and timing characterization [4]. In order to locate soft defects or to perform timing characterization, Dynamic Thermal Laser Stimulation (D-TLS) techniques have been developed. D-TLS can precisely and directly localize defects such as resistive path or shorts in the IC's that where not readily detectable by EMMI and sometime out of the range of conventional TLS technique. All DLS techniques are now widely used for a lot of debug purpose such as bottleneck isolation, margin issues and other design limit problems. It consists of scanning an IR laser over the front-side or backside of the device under test [10]. Upon laser beam irradiation, localized thermal gradients are generated in the IC's and slightly change the behaviour of the device under test. As an example, the following picture (figure 1), superimposing TLS and Laser image, was obtained on a ring oscillator.

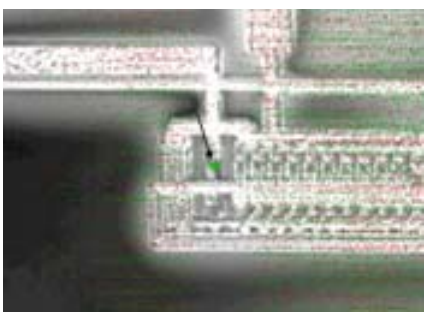


Figure 1. OBIRCH (Static Thermal Laser Stimulation) analysis at 50x

2.2 Emission Microscopy

Emission Microscopy (EMMI) is a very well known technique in failure analysis. It has been shown to be efficient in detecting a wide range of leakage defects in MOS oxides. The application of this technique to backside failure analysis is quite straightforward [10]. Emitted photons by the circuit under test are detected with a camera during some minutes of acquisition. Light emission images are acquired with camera illuminated in back or front side. As an example, the following picture (figure 2), superimposing EMMI and CCD image, was obtained on a ring oscillator on a 0.18µm test vehicle.

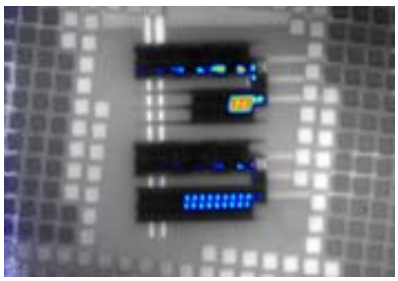


Figure 2. EMMI (Emission Microscopy) analysis at 100x

2.3 Time Resolved Emission

Time-Resolved Emission (TRE) (e.g. PICA [7], TRE [8] …) has the potential to identify faults by analysing the luminescence emission, as a function of time. It is an optical probe techniques. TRE gives waveforms coming from running gates. Waveform shapes and timing is more and more used for Debug and Failure Analysis.

TRE detectors provide time capabilities, but they have the disadvantage to be a single-point measurement, with no possibility to spatially map the luminescence emissions from the chip. In order to first localize the luminescence origin (e.g. a switching transistor or a faulty device within a chip), it is interesting to couple TRE equipments (i.e. time information) with light emission microscopes (i.e. spatial information) [9]. In figure 3, we used PMT detector to collect emission for different gate width down to 150 nm in 120 nm technology [11].

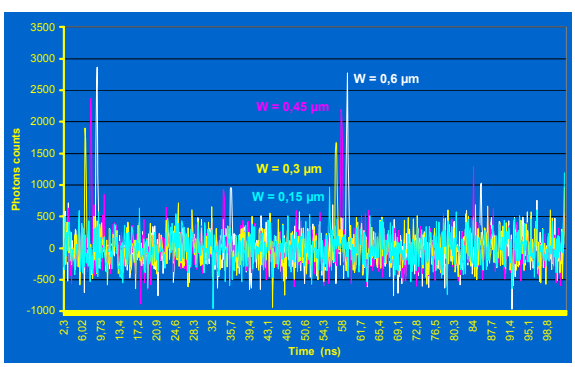


Figure 3. TRE (Time Resolved Emission) at 1.2V

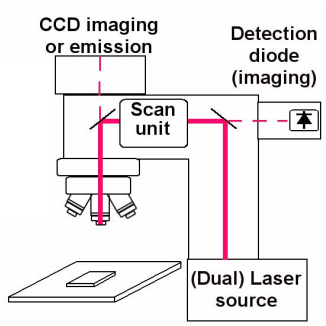
3 System

3.1 PHEMOS-1000 Hamamatsu

We use a Hamamatsu PHEMOS 1000 system to perform EMMI [3]. Throughout this study we used the Hamamatsu's backside illuminated CCD camera. Backside imaging is done through the silicon substrate using an infrared light. Then, the circuit is observed with the CCD camera through a NIR filter.
The system has been modified in order to perform experiments using EMMI, TRE and D-TLS on the same machine. These added are described in the following paragraphs.

3.2 D-TLS implementation

The D-TLS (Dynamic Thermal Laser Stimulation) method was implemented on the Hamamatsu PHEMOS 1000 emission microscope as well since it incorporates a NIR Laser-Scanning Microscope (LSM). The LSM uses a continuous wave IR laser with a wavelength of 1.3µm and an incident power of 100mW before the microscope objective. We can see scanning system on the scheme 1.
Frequency variations are measured during the Thermal Laser Stimulation with a spectral analyzer. The device under test is polarised and is electrically active. Then laser beam scans point by point a zone of the integrated circuit on analysis.



Scheme 1. Thermal Laser Stimulation path of our system

This energy modifies electric properties and disturbs dynamic behaviour of the circuit. Correlating perturbation measures with laser spot, we obtained cartography of different levels of perturbations induced by the thermal stimulation. We can easily identify zones abnormally sensitive and measure frequency variations on output of IC.

On figure 4 we can see, on the same structure (ring oscillator), that D-TLS induces an increase of frequency at the point number 1 and a decrease at the point number 2.

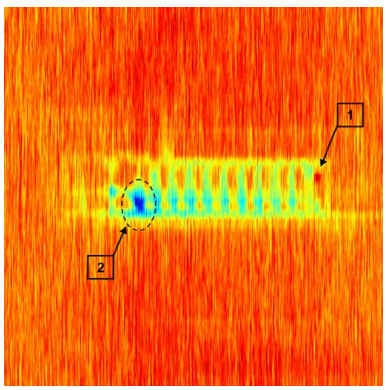


Figure 4. D-TLS Frequency Variation Mapping. Results on a ring oscillator

3.3 TRE implementation

For failure analysis, a combined system offering both time resolved photon emission and 2D emission is a wining solution [11]. Since no commercial systems are available at today's date, we have added the TRE detector onto the existing emission microscope.
Time-resolved photon emission (TRE) has been performed with PMT InGaAs module from Hamamatsu implemented on the PHEMOS-1000. This module collects photon with a resolution about 40ps.

4 Test vehicle

The experiments, presented in this paper, have been performing on a 0.18µm test vehicle. Vehicle test is driven by an electrical tester coupled on the PHEMOS-1000.
On this test vehicle, ring oscillator allows to measure the intrinsic gate delays. It is mostly dedicated to library characterization targetable by the study of propagation delays.
Studied chain contains 61 inverters loaded by 40 gates, and runs at 62MHz in oscillator mode. It should have been 64 MHz. Therefore, there is a discrepancy between measured and expected frequency. Why is thus frequency slightly slower? It could be a mismatch between models and silicon implementation, a design or a process issue.
We successively analyze our device with Dynamic Emission Microscopy, Dynamic Laser Stimulation

and Time-Resolved Emission in order to find the origin of this lower frequency.

5 Results

5.1 Emission Microscopy

The Dynamic Emission Microscopy acquisition is a static acquisition at frequency running device based on cumulative emission. The result can show less, more or the same emission than expected.
In our case, after 600s acquisition time with the 100x objective, we can observe that the functionality is good but we see an abnormal light emission on the inverter number 3 compared to golden inverter (figure 5). In this case, it is important to already underline that dynamic emission collected with static CCD detector gives us a localization of some slight dynamic issues.
At this state, we need to get timing information about this over emission. We used Time-Resolved Emission to get this timing information.

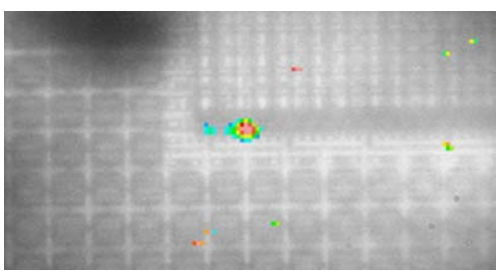


Figure 5. Inverters chain EMMI analysis at 100x

5.2 Time-Resolved Emission

We observe commutation peaks on TRE results (figure 6). We have emission peak when NMOS go from OFF to ON state. PMOS emission is weaker than NMOS one. So we can't look at PMOS. The delay between inverters 57 and 59 is around 150 ps while the delay between inverters 3 and 5 is 700 ps. TRE technique validates that the gate number 3 is slowly switching compare to the others inverters. Furthermore, the temporal width of signal from gate number 3 is greater than the others.
This analysis also confirms the important light emission level previously observed by Emission Microscopy. It is important to notice the good correlation between EMMI and TRE (waveform shape) and the new timing information collected by TRE.

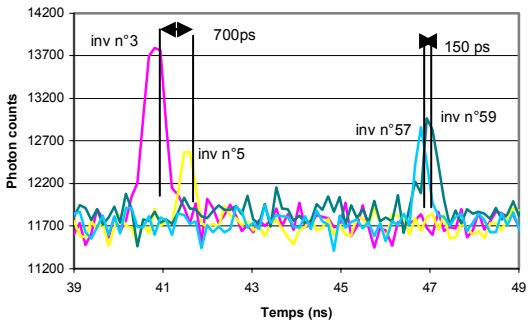


Figure 6. Inverters chain TRE measurements obtained on inverters 3, 5, 57 and 59

Emissive techniques summary : we showed the complementarity between EMMI and TRE. About the abnormal emission, we have no explanation for the higher peak, nevertheless we suspected a resistive via between two inverters. We still need complementary experiments using Dynamic Thermal Laser Stimulation (D-TLS).

5.3 Dynamic Thermal Laser Stimulation

Frequency is the key parameter for ring oscillator. Analog frequency mapping using Delay Variation Mapping (DVM) allows us to look at this key parameter.
DVM results (figure 7) indicate that heating the gates by the laser beam reduces the oscillation frequency of the inverter gate chain (nominally around 64MHz). A greater frequency shift is observed on the inverter number 3.

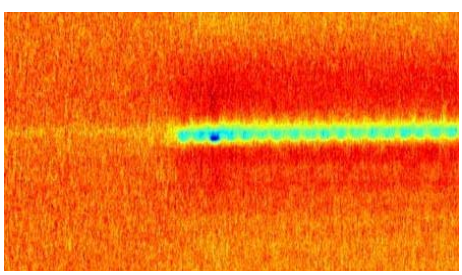


Figure 7. Inverters chain D-TLS analysis at 50x

D-TLS results correlate previous experiments performed with Emission Microscopy and TRE and gives us a new information: the thermal sensitivity of the defect.

6 Discussion

With Emission Microscopy, we localized abnormal emission on the inverter number 3. Defect localization is done but what kind of defect is it?
There is no leakage at steady state therefore no short circuits a bridge defect.
Timing recorded by the TRE corroborates EMMI result, but it is not possible to go further. TRE mostly underline transitions from NMOS off to NMOS on and we did not get information of transition from PMOS off to PMOS on or this information was hidden by noise. Waveform and time measurement are compliant with a lot of hypothesis.
D-TLS gave us complementary information about the thermal sensitivity of the defect. We suspect that this is due to a slightly resistive contact between metal 1 and poly gate that slow down the transitions from low to high and high to low.
Assumptions on the defect can be done. We could simulate defect effect under laser stimulation in order to validate these assumptions. It could be a very powerful approach to help failure analysis process.

7 Conclusion

In this paper experimental studies have been carried out combining dynamic emission microscopy, Time Resolved Emission and Dynamic Thermal Laser Stimulation. Technique complementarities has been underlined as well as how we can use fault isolation and timing characterization results to build some failure mechanisms hypothesis.
The great interest to have all these techniques on the same system is that we don't need to change electrical setup of the device, nor to modify alignment, probe card and tester. We can perform analysis under the same conditions using Emission Microscopy, Time-Resolved Emission and Dynamic Thermal Laser Stimulation.
When we begin a failure analysis, we don't know exactly what technique would be the most interesting to bring out defects or fault isolations. It would be important to define an investigation method to realize a failure analysis. Our current work is to continue investigation in order to enhance our knowledge on dynamic optical techniques for failure analysis. The final proof will be done by physical analysis.
For space applications, reliability demands are very severe. Changing a fail component on a in flight satellite is impossible. Components design and process are getting more and more complex, therefore it is very important to identify design and process faintness in order to evaluate their reliability risk.

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