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Analysis of semiconductor fault using DS (damped sinusoidal) HPEM injection

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ABSTRACT

Electronic systems based on solid state devices have changed to be more complicated and miniaturized as the systems developed. The evaluation of HPEM (High Power Electromagnetics) has been mainly carried out in the system level, and the case of failure analysis on the device is very rare.

If the electronic components (semiconductor) are exposed to HPEM, the semiconductor will be destroyed by the coupling effects of electromagnetic waves. Because the HPEM has fast rise time and high voltage of the pulse, the semiconductor is vulnerable to external stress factor such as the coupled electromagnetic pulse. By injecting Damped Sinusoidal Pulse to the semiconductor devices, were observed the increase of leakage current and the physical damage.

Preferred presentation:
[ ] Oral
[o] Poster
[ ] No preference

Preferred track (please, tick one or number 1 to 3 tracks in order of preference: 1 = most suiting, 3 = least suiting)

[2] A - Quality and Reliability Assessment Techniques and Methods for Devices and Systems
[ ] B1 - Si Technologies & Nanoelectronics: Hot Carriers, High K, Gate Materials
[ ] B2 - Si Technologies & Nanoelectronics: Low K, Cu Interconnects
[ ] B3 - Si Technologies & Nanoelectronics: ESD, Latch-up
[3] C - Progress in Failure Analysis: Defect Detection and Analysis
[1] D - Reliability of Microwave and Compound Semiconductors Devices
[ ] E1 - Power Devices Reliability: Silicon and Passive
[ ] E2 - Power Devices Reliability: Wide Bandgap Devices
[ ] F - Packaging and Assembly Reliability
[ ] G - MEMS, Sensors and Organic Electronics Reliability
[ ] H - Photonics Reliability
[ ] I - Extreme Environments and Radiation
[ ] K - Renewable Energies Reliability
[ ] L - Modeling for Reliability
[ ] SS1 (Special Session) - Reliability in Traction Applications

1. Introduction

The high altitude electromagnetic pulse can be generated by nuclear and non-nuclear means. It poses a serious threat to electronic systems and electronic components [1].

Modern civil systems are based on electronic components and subsystems composed of electronic parts. The undisturbed operation of electronic equipment is of vital importance for the function of traffic systems (airplanes, traffic guidance, etc.), security systems, and communication in modern, developed nations. A malfunction in one of these areas could cause ecological and economical disasters [2, 3].

Fig. 1 illustrates the simplified High Power Electromagnetic (HPEM) environment. Therefore, the susceptibility of electronics to pulsed

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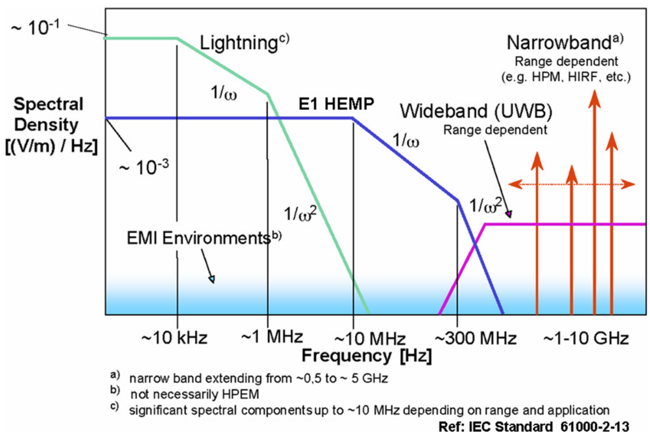

Fig. 1. HPEM environment.

electro-magnetic fields like EMP is of great interest [4].

The IEC standard and technical reports on High-altitude EMP (Electromagnetic Pulse) have been mainly published on evaluation standards for systems and fixed facilities, yet no standard document on individual semiconductor devices has been published [5–11] (Fig. 2).

We carried out injection tests of a high altitude electromagnetic pulse (HEMP) where a frequency component of 80 MHz to 500 MHz generated from a damped sinusoidal electromagnetic pulse generator corresponding to IEC 61000-4-36 is applied to a printed circuit board through radiation [12].

The experiment was conducted on a semi-conductor component (phototransistor 6N139) mounted on a printed circuit board and confirmed the internal physical damage of the phototransistor where the malfunction occurred.

2. Experimental information

2.1. Test PCB

It may be necessary to begin with a brief history of the boards used in this test. This test board was first used in a nuclear power plant and had a history of replacement due to functional problems. After that, the cause of the failure was analyzed and it was proved that there is a fault in the device that processes the input of the logic circuit. To be more precise, in Fig. 3, a defect in the On/Off function of the phototransistor in the red circle was found.

The reason for replicating the pattern of this test board is that the radiated DS HPEM is known to affect the device by being coupled to the copper pattern of the board. Thus the position and length of the copper pattern in the board is a very important factor in HPEM experiments [13, 14] (Fig. 4).

For this experiment, we exactly replicated the manufacturer, the position of the parts, and so on of the original board. It took a great deal of time and effort to understand the information on the board as it was built and used 20 years ago in order to make it exactly the same again.

2.2. Victim

The part that caused the problem with the defect on the test board is the 6N318 (High Gain Darlington Phototransistor), shown in Fig. 5. In a Phototransistor with a defect, even if a turn-on voltage (V_f) is applied to the input LED (between pin 2 and 3), the phototransistor is not completely turned on and a considerably large V_{ce} voltage is detected.

2.3. DS HPEM source

We carried out injection tests of a high altitude electromagnetic pulse (HEMP) where a frequency component of 80 MHz to 500 MHz generated from a damped sinusoidal electromagnetic pulse generator corresponding to IEC 61000-4-36 is applied to a printed circuit board through radiation. Table 1 shows the specifications and characteristics of the DS HPM source used in the test (Fig. 6).

Table 1 and Fig. 7 show the specifications and characteristics of the DS HPM source used in the test.

2.4. Electromagnetic field strength

It is useful to measure the exact value of the electromagnetic field strength that is applied to the victim, but the HPEM is very difficult to measure because it occurs very momentarily. Moreover, the EM field may experience distortion when HPEM is emitted by a conductive structure. The EM field strength measurement technique of the E-field caused by HPEM is another area of study.

As a next step, we chose a method of estimating the EM field value at the location of a victim by measuring the value of the EM field radiated from DS HPEM by distance.

Fig. 8 shows the test setup to verify the compatibility of the

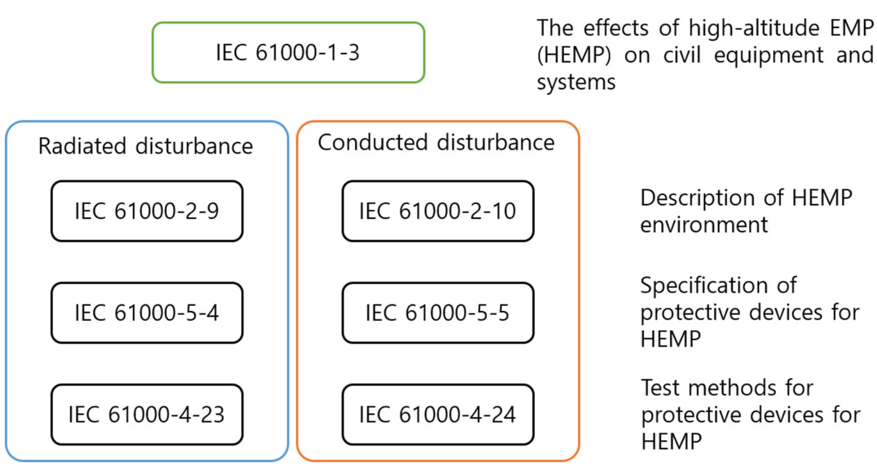

Fig. 2. International standard for HEMP protection.

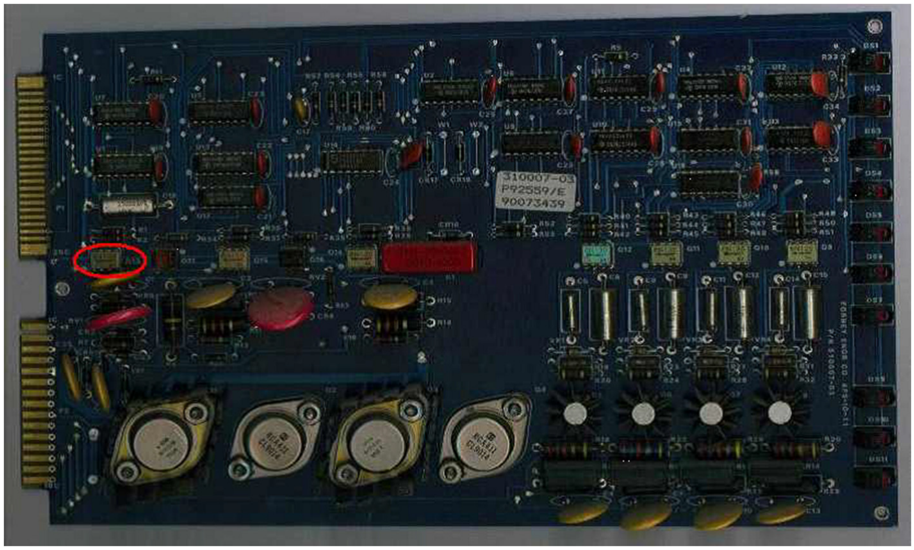

Fig. 3. The original board.

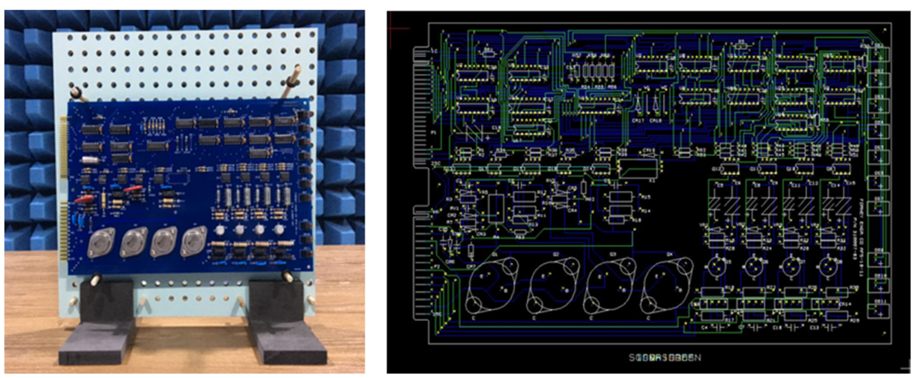

Fig. 4. The replicated test PCB.

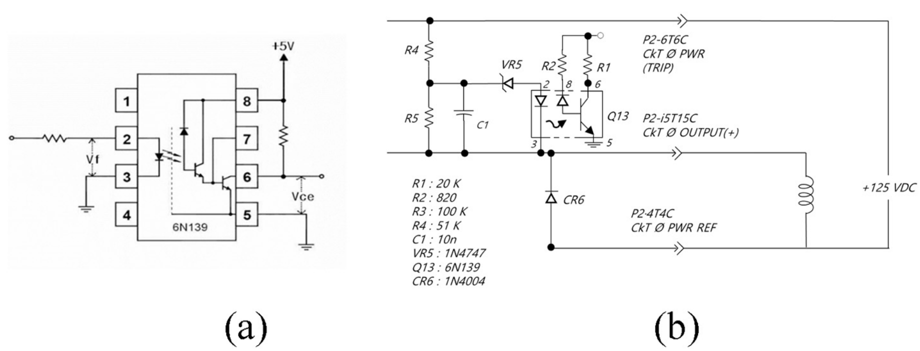

Fig. 5. (a) 6N138, (b) test circuit for HEMP.

Table 1
DS HPEM simulator specifications.

Category	Specification
Peak E-field strength	12 kV/m@10 m
Center frequency	80–500 MHz
Damping factor	1–20
Bust duration	1–10 s
Pulse repetition frequency wave form	1–10 Hz Damped sinusoidal
Far voltage (rE)	125 kV

anechoic chamber under test by measuring the electromagnetic field strength along the distance. Fig. 9 shows that EM field strength (E) exhibits relatively linear attenuation. (* "rE" is the measured value, and "E" is the calculated value.) If the anechoic chamber is not shielded from the external electromagnetic environment, or if the HEMP radiated is not absorbed from the wall, this conversion value "E" (kV/m) may not be linear.

Therefore, we verified the compatibility of the experimental space with the distribution of E (kV/m) values of rE (kV) divided by distance (Fig. 10).

Fig. 6. DS HPEM source in anechoic chamber.

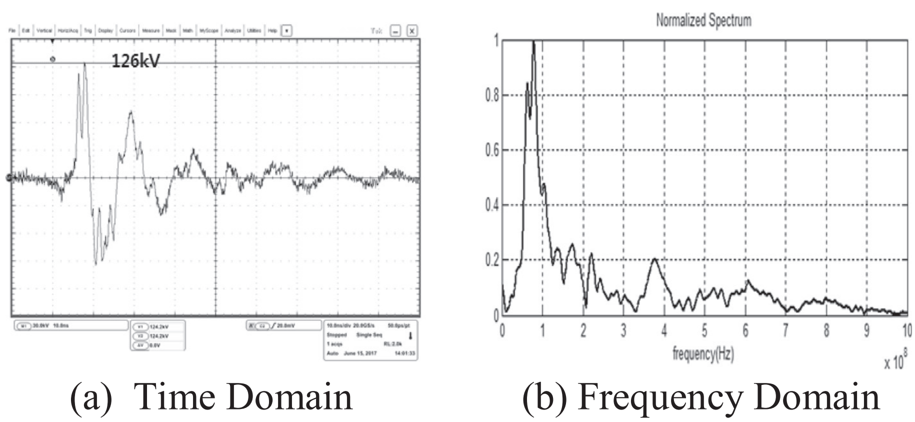

Fig. 7. DS HPEM source characteristics (@10 m).

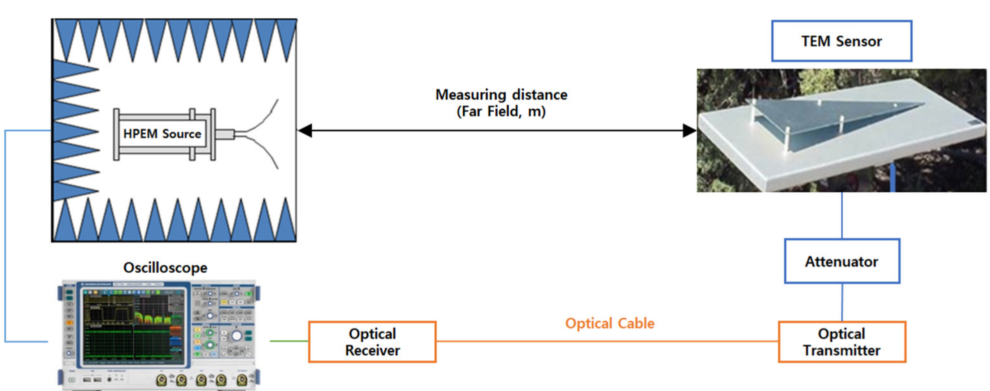

Fig. 8. EM field measurement setup.

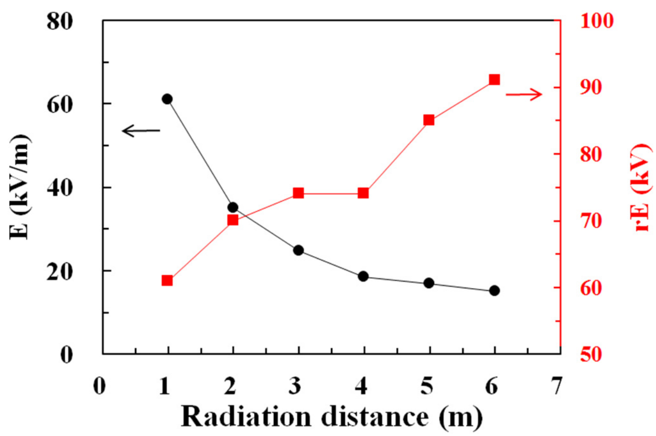

Fig. 9. EM field strength.

3. Experimental setup

All experimentation was carried out in the Korea Electronics Technology institute (KETI) Anechoic chamber. A special camera with protection against HPEM was used to monitor the real time status of the test board. When the HPEM is radiated from the DS source to the target board, the HPEM is coupled to the V_{ce} (between pin 5 and 6) as shown in Fig. 5, and the operation of the board is stopped in an instant. This phenomenon can be confirmed by the scope.

Fig. 11 shows a flow chart for evaluating the effects of the semiconductor devices on HPEM.

Since the intensity of the EM field is linearly damped in proportion to the set distance, we evaluated the influence of the test device by moving the source at intervals of 1 m starting from 6 m and ending at 1 m. The reason for adjusting the EM field intensity applied to the sample by adjusting the distance is that the IEC 61000-4-36 standard specifies only the peak E-field strength of the DS HPEM simulator at 10 m to 12 kV/m.

4. Results

At a distance of 2 m between the source and the victim, the LED of some tested 6N139 input section was opened and it was confirmed that malfunction occurred. The characteristics of the parts (6N139) emitted by the HPEM source were measured using a curve tracer.

Fig. 12 shows the waveforms measured by oscilloscope for the coupling phenomena measured in V_{ce}. The coupling phenomenon is not limited to V_{ce} but occurs throughout the target board. For this reason, the magnitude of the pulses measured by the oscilloscope becomes very unreliable and is used only to confirm that the coupling phenomenon has occurred.

In Fig. 13, DS HPEM injection has induced physical damages shown by the analysis of the sample. An emissive microscope was used to analyse the internal defect inside the phototransistor. The leakage current increased due to the internal defect (damage) at the base end, and the occurrence of the defect was confirmed.

It was confirmed that the IC value (@V_{ce} 20 mV) of the Phototransistor at the output part of the phototransistor tested at the emission distance of 2 m was increased by about 100 μA, from 879 μA to 1004 μA, as compared with that of the normal parts. The increase in the leakage current injected by DS HPEM was caused by physical damage of the semiconductor.

Emission Microscope (EMMI) is well known to detect induced physical damage both at the gate and junction levels [15]. EMMI is able to detect the defect only if the leakage current was in the μA range. Semiconductor defect resulting from HPEM injection is the cause of the observed leakage current increases.

Despite the leakage current, specimen functioned normally. Therefore, it can be inferred the leakage current is allowed in the product. Fig. 14 shows the leakage current at the p-n junction caused by the fault injection.

5. Conclusion

The evaluation of HEMP has been mainly carried out on the system level, and failure analysis on this device has been very scarce.

In this study, it is important to assess the effects of HPEM on the chip level. We analyzed the state and characteristics of the

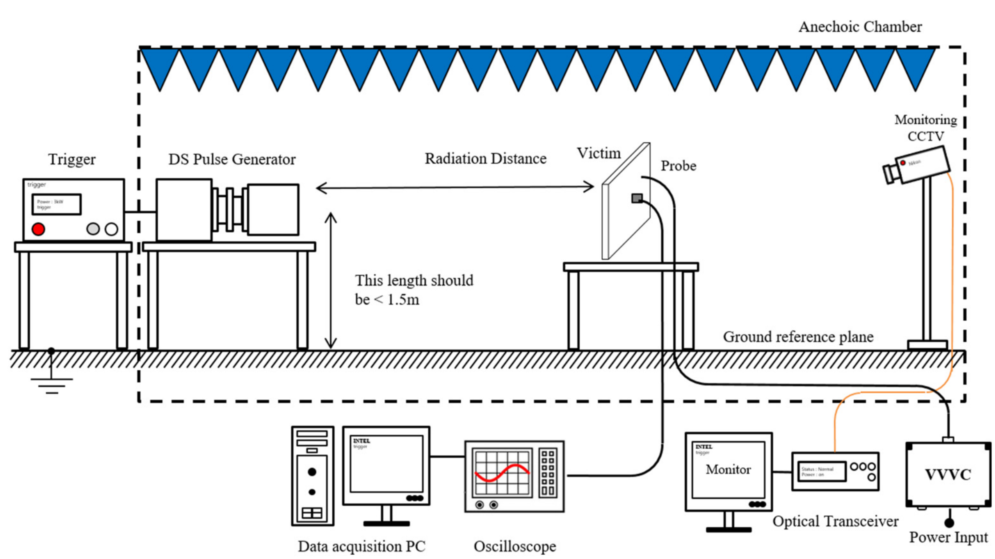

Fig. 10. EMP injection test configuration.

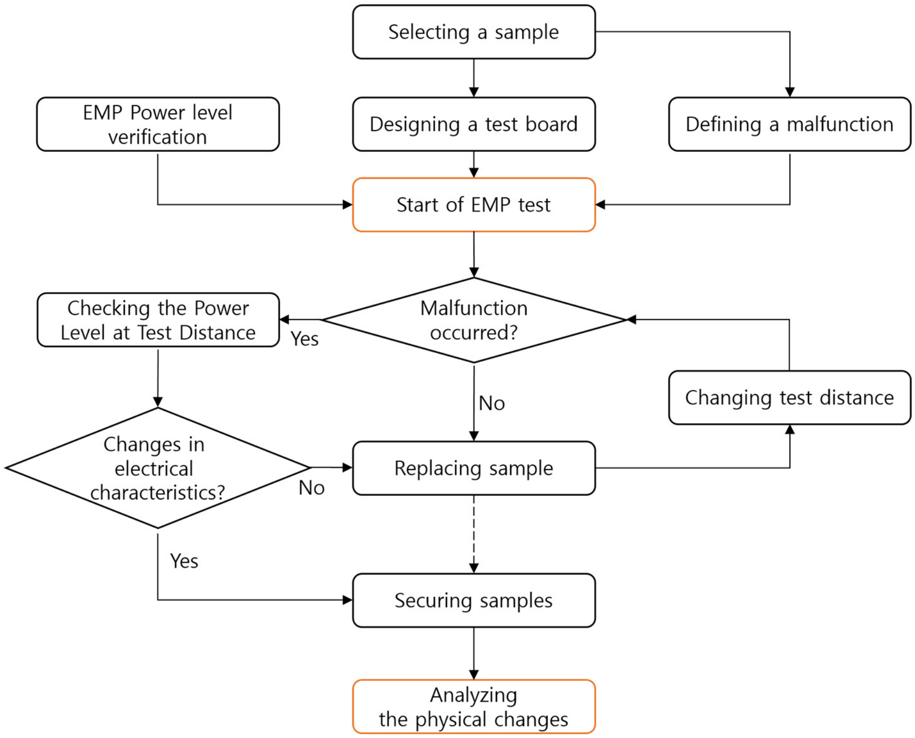

Fig. 11. Fault injection test sequence.

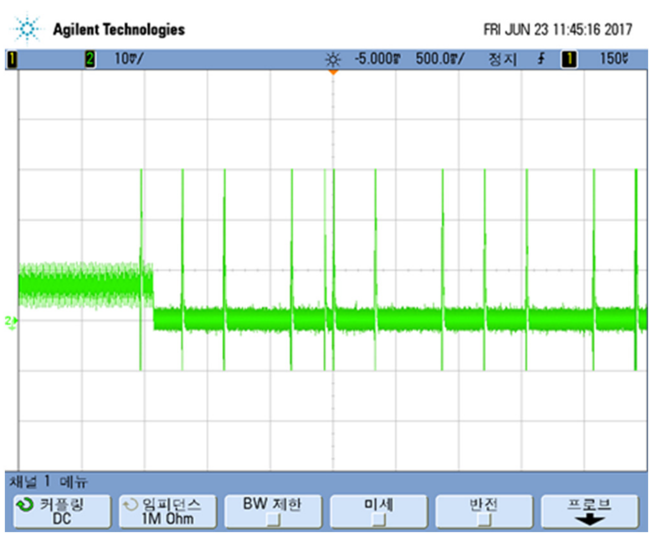

Fig. 12. Coupling phenomenon at V_{ce}.

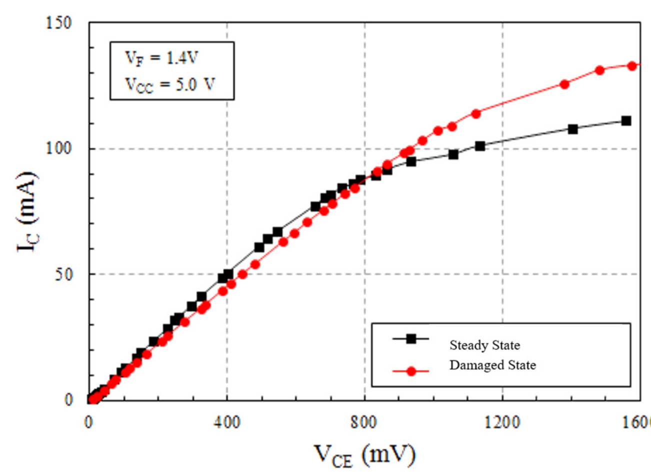

Fig. 13. Curve tracer measurement results.

semiconductor mounted on printed circuit board by DS (damped sinusoidal) HPEM. It was confirmed that the current characteristics change according to the voltage of the diode and the transistor in the phototransistor.

The empirical finding obtained from many experiments is that if the device is not powered on, the malfunction does not occur and the failure of the device cannot be checked in real time.

We plan to continue research on how substantial energy is actually successfully applied to the chip level. Our researchers plan to continue to study the effects of other devices and other EMP sources as well.

Acknowledgements

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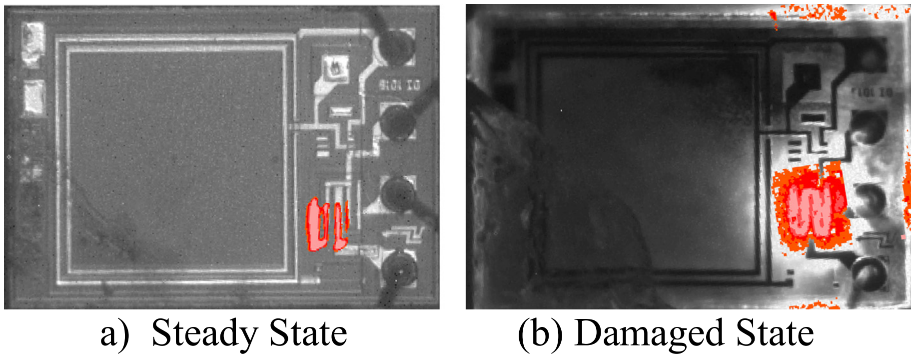

Fig. 14. Leakage current position inside the photo-transistor using the Emission Microscope (red part). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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