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Lock-in thermography for defect localization and thermal characterization for space application

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ABSTRACT

Non-destructive failure analysis and defect characterization are necessary steps for every component that is destined to space projects. Infrared Thermography is a non-invasive, contactless technique providing information regarding defect localization as well as thermal characterization. The system used in CNES Expertise Laboratory is a DCG ELITE system equipped with an InSb camera that detects IR between 3 and 5 μm. Defect localization could be done in steady state observation, where the Device Under Test (DUT) is observed in nominal condition for hot spot localization. The spatial resolution for the localization of defect heat sources could be improved by a lock-in mode, also known as phase sensitive modulation thermography. Defective or not, the component can be thermally characterized by time related heat propagation. Here the origin of the heat source is visualized, and the temperature measurements give a thermal map of the DUT. Both defect localization and thermal characterization are possible on board and component level, and their utilization will be illustrated by studying case analyses.

1. Introduction

Major types of possible faults in microelectronic and electronics devices are local exothermic faults, like electrical short circuit, high resistance open, junction breakdowns, dielectric leak … For these defects characterized by an hot spot creation, several thermography techniques for microelectronic devices have been developed such as photon emission microscopy (PEM), liquid crystal thermography (LCT), thermo-reflectance microscopy (TRM), steady-state infrared thermography (IRT) … [1–3]. In the CNES Expertise Laboratory, non-invasive methods such as IR thermography are key instruments to locate defects on equipment that should not be contaminated or touched even with a simple probe needle. In this paper the utilization of IR thermography will be illustrated by two case studies from populated board to single device characterization.

The Infrared Thermography system used is a DCG (now FEI EFA group solution) ELITE system, equipped with an InSb camera and four lenses. This equipment receive infrared wavelength between 3 and 5 μm at a spatial resolution about 3 μm with the 10× lens. This noncontact technique could give information on a wide area (16 × 20 cm with the Wide Angle lens) and also on the component scale. Infrared thermography can be divided in two types: active thermography and passive thermography. In active thermography, thermal phenomena need to be activated by an external stimulus, while in passive thermography the camera is just displaying an IR image of the scene [9].

The first part of this paper will deal with lock-in thermography that is part of active thermography, with an electrical stimulus synchronized with the IR camera. Here lock-in thermography is done on a defect ceramic capacitor. The second part of the paper deals with temperature measurement, being a passive thermography technique, on a high frequency Gallium Nitride (GaN) transistor.

2. Defect localization

Defect localization with IR thermography could be done by two mode, steady-state and lock-in mode. In steady state mode, the camera is passive and observes the board or the component in its nominal mode of operation. In lock-in mode, the principle is to apply a modulated bias to the device under test (DUT), that induces periodical thermal emission. The latter depends on physical and thermal material properties, but also on the emission source depth in the DUT. This emission, captured by an infrared camera, provides information about the amplitude and the phase delay of the thermal response of the component to the modulated bias. [4] In lock-in mode, thermal wave propagation on the DUT is limited, and the precision of defect localization is generally better. This precision is then dependent on the characteristics of the

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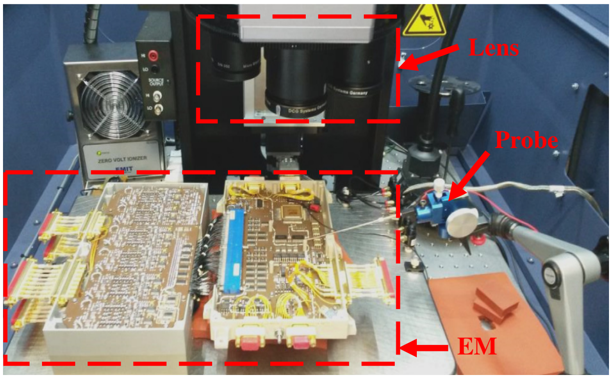

Fig. 1. Engineering model under the IR camera.

device under test and on the lock-in settings. A principal parameter to take in account among the lock-in mode settings for defect localization is the lock-in frequency. Indeed, the higher the frequency; the more accurate the heat source localization. However, in some cases the emission of the defect is not sufficient, and the frequency needs to be decreased in order to detect more photons on the IR sensor.

2.1. Case study presentation: defected capacitor

During environmental life test, a flight model of a satellite payload instrument has shown power overconsumption. Following the space expertise process, the engineering model (EM) has been analysed first of all, in order to identify the power overconsumption issue.

Firstly, for reasons described in the introduction, we choose to use infrared thermography techniques. Being contactless and non-invasive, they could allow one to locate areas of anomalies areas on the EM that can be related to the flight model failure.

The EM has been powered nominally under the IR camera, as shown in Fig. 1, in complement to specific electrical characterization and diagnosis.

A thermal signature has been located on a decoupling capacitor. At this point, the main hypothesis is that this “hot spot” can be caused by leakage current in the identified capacitor. In fact a leakage current located on this decoupling capacitor (Fig. 2) can be a root cause of the overconsumption of the flight model.

In a second step the EM board has been placed in an environmental life test, in order to reproduce the life condition of the flight model and

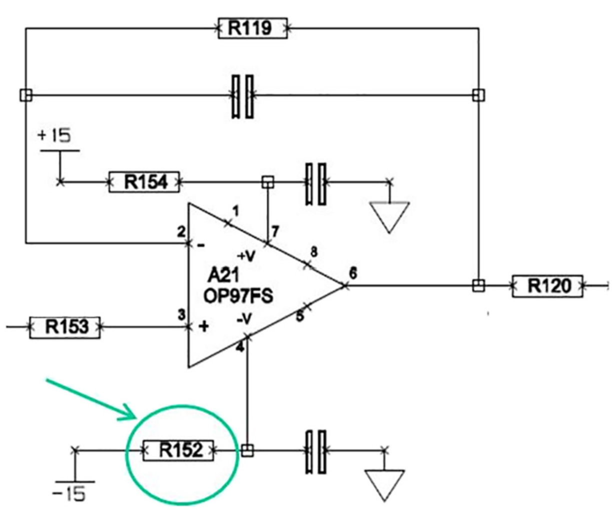

Fig. 2. Part of the electrical scheme with the supposed defected capacitor (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

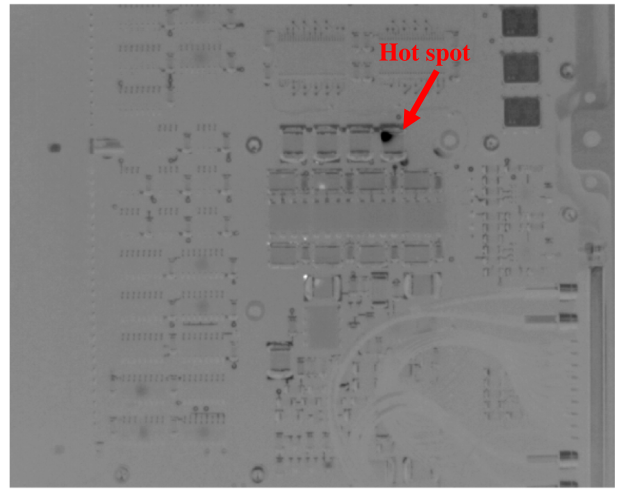

Fig. 3. IR image in steady state of the board nominally powered before life test environment (Wide angle lens).

to follow the evolution of capacitor's electrical parameters. This environmental test takes place in a vacuum chamber, where pressure and temperature are controlled. System power consumption and temperature in different locations are measured during the test, as we are looking for a power overconsumption as for the flight model.

2.2. Steady state mode

Before having been exposed to the environment life test, the EM payload has been analysed by means of the steady state mode of the IR camera. In steady state mode analysis, the EM payload is powered nominally and observed with the IR camera. Another steady state observation will be made after the environment life test for comparison.

The electrical status before the life test was that there was no electrical signature of a defect. Only a thermal observation (Fig. 3) of a defect on one of the ceramic capacitors on the board has shown a hot spot.

Fig. 3 represents in grey scales the IR image of the board nominally biased. One of the capacitors present on the board shows a local temperature elevation. This hot spot could be the origin of the failure. After performing a local electrical probing test on this capacitor terminal, a leakage current in order of few nano-amperes has been measured.

After this the payload has been placed in the life test environment, to reproduce FM environment conditions when the defect appears. During the test, the EM payload showed a power overconsumption similar to the flight model. Because of this, the life test has been immediately stopped, and another steady state analysis has been performed in complement to electrical characterization.

Fig. 4 represents defect evolution before and after environmental life test in steady state IR observation. On the “after test image”, the top

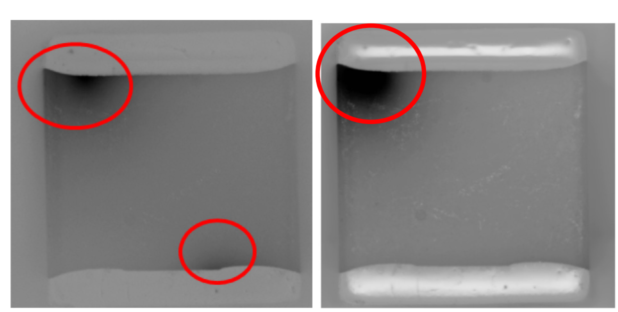

Fig. 4. IR image of the defected capacitor before (left) and after (right) environment life test (both 1 × lens).