Reliability of IR Components for Gas Sensing Applications

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New reliability stress-testing standards and procedures were established for qualification of IR components, which find their applications in various domains, such as energy, transportation and health diagnostics. The functional lifetime was calculated based on accelerating aging models and test results. The broad variety of components and their application domains required a special care to adapt the reliability evaluation tests and procedures. Performed failure mode analysis allowed the understanding of the failure root causes. The investigations were carried out in collaboration with the IR source and detectors manufacturers within the framework of an EU project (MIRPAHB). This project focuses on the development of a pilot line for providing a unique chemical detector spectroscopic system by combining mid-infrared sources, photonic circuits and detectors in a standard packaging. One of the major challenges in such a pilot line is to establish a common procedure for qualification of various components from different manufacturers in order to ensure their lifetime and compatibility in a common package.

The aim of MIRPAHB project is to set up an all-service integrated pilot line for the development of mid-IR photonics gas sensors from the IR components available in Europe. Mid-IR spectroscopy of molecular vibrations enables accurate and precise determination and quantification of various gases based on their spectroscopic response (Figure 1).

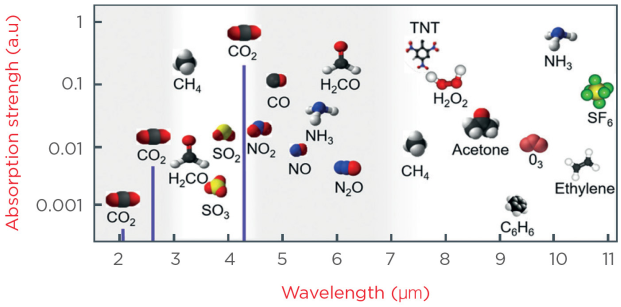

Figure 1: Absorption wavelengths and strengths of various gases.

The pilot line concept implies a selection of the proper source, detector and other components from the available list. Various components can be combined in the final system, similar to the Lego building blocks. This allows fine-tuning of the wavelength window and sensitivity to design the most suitable system for each specific customer application.

The pilot lime aims to achieve the TRL 8 to 10, which requires complete qualification of the final devices. In order to assure the necessary lifetime of the final system, there shall be a common qualification methodology for constituent components of the system. CSEM in partnership with the IR component manufacturers has established such a methodology. The approach is based on the analysis of the component integration level, and specific stress factors and environmental conditions that act on the system during its operation. Based on this analysis, we have defined 4 component integration levels (Figure 2):

- Level A: bare chip
- Level B: chip on a carrier (*e.g.*, sapphire or AlN plate)
- Level C: chip mounted on a thermoelectric cooler (TEC) without packaging
- Level D: chip mounted on a TEC and hermetically sealed

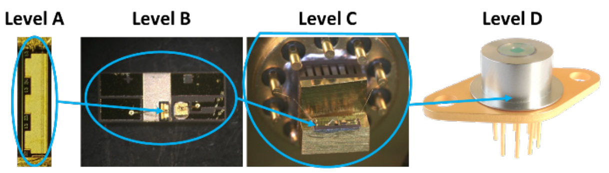

Figure 2: Integration levels of IR components (example: mid-IR laser).

Depending on the component integration level and the expected operation conditions (normally T=25°C and RH~40-50%) the following corresponding reliability stress-tests shall be performed:

- Temperature-accelerated lifetime test (levels A, B, C, D)
- Temperature cycling test (levels A, B, C, D)
- Temperature-humidity bias test (level D)
- Mechanical shock test (level D)
- Mechanical vibration test (level D)

The developed stress-test procedures reflect different possible system use conditions by defining test load severity levels. This allows to qualify the components and to estimate their expected lifetime for the defined use conditions using the Arrhenius law for T-accelerated lifetime tests:

$$R(T) = \gamma_0 \exp\left(\frac{-E_a}{kT}\right)$$

The failure assessment is based on the measurements of certain electrical and optical characteristics of the tested components before and after the test. Figure 3 shows an example of the I-V characterization curves of an IR detector subjected to temperature-accelerated lifetime test. The device has passed the test at 125°C for 1000 h without a failure. Using the Arrhenius law, the component lifetime can be calculated: ~100 years at the use temperature of 25°C and ~20 years at the use temperature of 45°C.

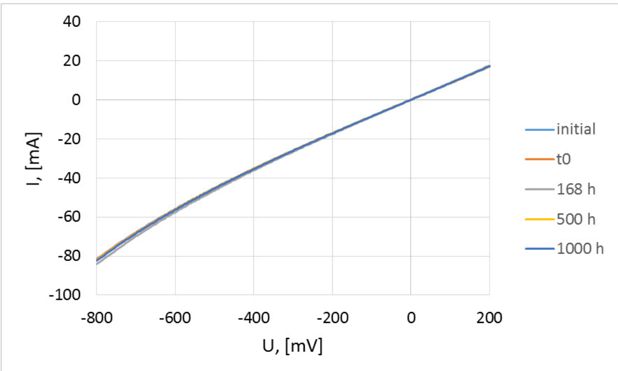

Figure 3: I-V characteristics of an IR detector subjected to T-accelerated lifetime test. A close overlap of the curves indicates no device failure.

Verification of the developed methodology and test procedures was accomplished by carrying out of the tests on real devices. Necessary adjustments to the test conditions were made based on the results of the test campaign. The finalized test procedures will serve as test standards for qualification of newly developed IR components for their use in the pilot line.