A NEW METHOD TO ASSESS THE HERMETICITY OF MEMS MICRO-PACKAGES

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INTRODUCTION

Hermeticity is one of the main reliability issues for MEMS packaging. Actually, with their released and mobile parts, MEMS are very sensitive to numerous failure mechanisms dependent on their operational environment such as stiction or charging effects. Moreover, particular devices like resonators may exhibit large functional variations dependent on the composition of their close atmosphere. So, it is necessary to assess and control precisely the hermeticity of MEMS micro-packages.

Most of the time, hermeticity measurements are performed by helium leak detection using a mass spectrometer, as specified in the MIL-STD-883 standard, method 1014 [1]. Nevertheless, several studies have proven that this detection technique is not adapted to micro-cavities with a volume of 10 mm^3 or less [2] [3]. Consequently, it should not be used to assess the hermeticity of MEMS micro-packages, which often have volumes of 1 mm^3 or less. Moreover, due to the slow diffusion of gases into polymers, helium leak tests are not appropriate to measure the hermeticity of organic adhesive bondings, commonly used in MEMS wafer level micro-packaging. So, it is necessary to develop new techniques able to detect small pressure variations in small micro-packages. This paper presents one promising technique, using Fourier Transform Infra Red (FTIR) spectroscopy.

USE OF FTIR SPECTROSCOPY FOR THE HERMETICITY ASSESSMENT OF MICRO-CAVITIES

Fourier Transform Infra Red Spectroscopy Principle

The infrared spectroscopy is an analysis method based on the absorption of infrared rays by molecular linkages. Plotting the infrared spectrum transmitted through a material, we obtain absorption peaks that are characteristic of the different molecules present in this material. Using a spectra database, it is thus possible to determine qualitatively the composition of materials. For instance, Fig. 1 presents the infrared transmission spectrum of a commercial adhesive. Thanks to the Beer-Lambert's law, it is also possible to link the size of the different absorption peaks to concentration values, and then to analyze quantitatively the composition of the tested materials.

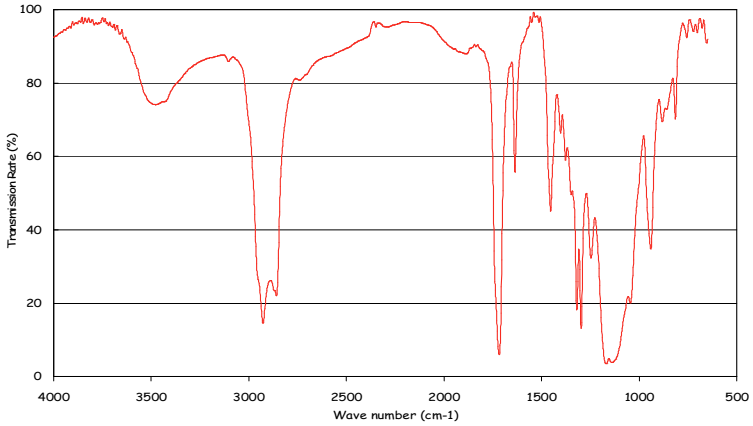

Fig. 1. IR transmission spectrum of the Loctite 222 adhesive

Application to the Hermeticity Assessment of MEMS Micro-Packages

Infrared spectroscopy, initially dedicated to chemical or material analysis, can be adapted to assess the hermeticity of MEMS micro-packages [4]. Indeed, classical materials used for chip or wafer-level packaging such as silicon and glass, can be considered as transparent for the IR wavelengths. It is thus possible to measure the IR absorption peak of a tracer gas contained in a MEMS micro-package by transmission through the cavity to monitor the internal gas concentration, and to check by this mean the hermeticity of this package (Fig.2).

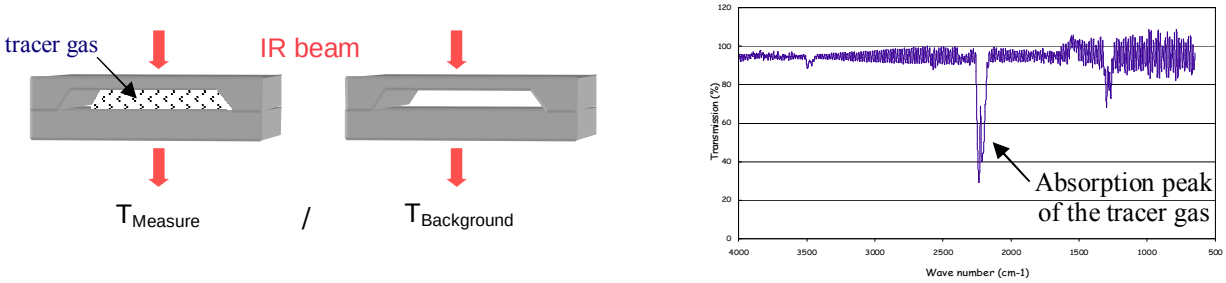

Fig. 2. Principle of hermeticity assessment by FTIR spectroscopy

It is even possible to quantify the internal gas pressure using the Beer-Lambert's law, as specified for the classical material analyses [5]. The Beer-Lambert's law links the measured transmission rate for the absorption peak to the internal concentration of the tracer gas. Assuming that this tracer gas is an ideal gas, it is thus possible to calculate the internal partial pressure inside the cavity (Eq. 1).

$$-\log(T) = \frac{d\,a}{R\Theta}\,p \tag{1}$$

Where T is the measured transmission rate for the absorption peak, d the depth of the cavity in cm, a the molar absorption coefficient of the gas for the specified wavelength in $L.mol^{-1}.cm^{-1}$, R the universal gas constant (0.082 $L.atm.K^{-1}.mol^{-1}$), Θ the temperature in K and p the partial pressure of the tracer gas in bar or atm.

Choice of the Tracer Gas

In order to obtain the best possible accuracy for the hermeticity assessment, it is important to choose carefully the tracer gas. It must have a low molar mass in order to minimize the time necessary to fill the packages before the measurements, and it must present an important absorption peak in the mid-IR domain (500 cm^{-1} to 4000 cm^{-1}) to be detectible by infrared spectroscopy. With a molar mass of 44 $g.mol^{-1}$ and two main absorption peaks for the 2210 cm^{-1} and 2240 cm^{-1} wave numbers (Fig. 3), nitrous oxide (N_2O) seems to be the best candidate.

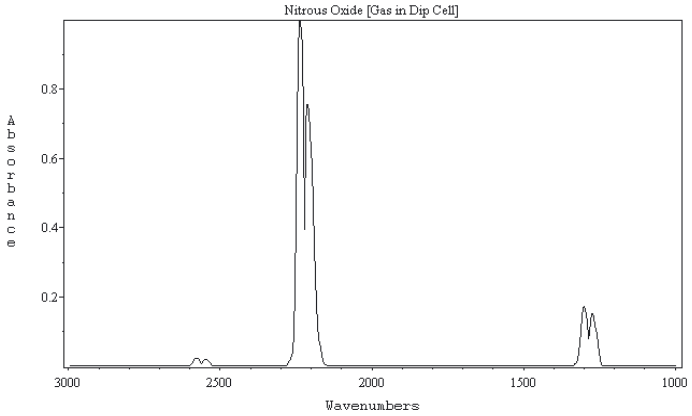

Fig. 3. Nitrous oxide absorption spectrum

Other gases like SF_6, OCS, HCl and H_2S could be used instead of N_2O [4], but they are all toxic except the first one, which presents a molar mass of 146 $g.mol^{-1}$. So we chose nitrous oxide for our hermeticity measurements.

EXPERIMENTAL MEASUREMENTS ON ORGANICALLY SEALED MICRO-PACKAGES

Fabrication of the Test Vehicles

FTIR spectroscopy was tested on micro-packages fabricated under CNES contract by the CEA-LETI laboratory in Grenoble. The packages were fabricated using a wafer level packaging technique, which was divided in two separate steps: the preparation of the top wafer and the sealing and dicing of the micro-cavities.

The first step was the fabrication of the lids for the micro-packages (Fig. 4). A silicon wafer with a thickness of 450 µm was first oxidized. Then the cavities were patterned and the oxide was etched. After the cleaning of the resin used for the patterning step, a KOH etching was carried out to obtain cavities with a depth of 350 µm. The preparation of the lids ended with a SiO_2 etching to remove the oxide from the top and the side of the wafer.

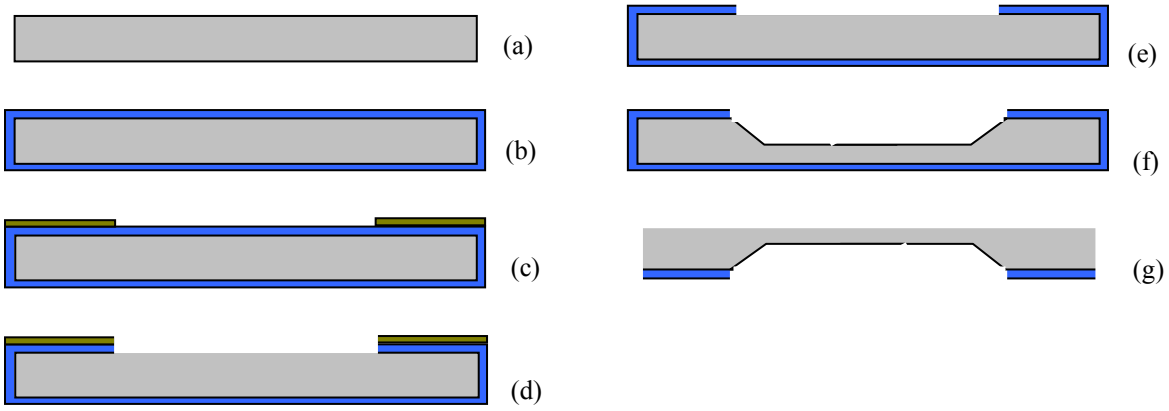

Fig. 4. Fabrication procedure of the top wafer: (a) 450 µm thick silicon wafer; (b) 2 µm thermal oxidation; (c) photolithography of the micro-cavities; (d) SiO_2 dry etching; (e) resin cleaning; (f) 350 µm KOH etching; (g) SiO_2 dry etching

Once the top wafer was prepared, the packages were sealed and diced (Fig. 5). BCB sealing rings were patterned on the substrate wafer using BCB (BenzoCycloButene) 4024-40. Then the lid wafer was put on the substrate wafer and the two wafers were sealed at 250°C under secondary vacuum (5.10^{-4} mbar). The last step was the dicing of the wafers into individual micro-packages.

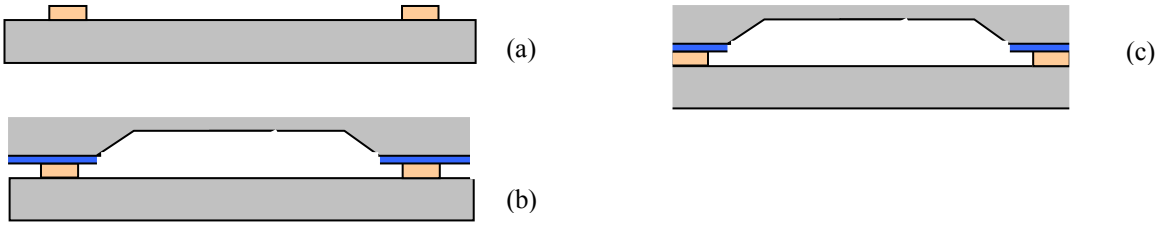

Fig. 5. Sealing and dicing process: (a) patterning of the BCB 4024-40 sealing rings on the substrate wafer; (b) sealing of the micro-cavities at 250°C and under secondary vacuum (5.10^{-4} mbar); (c) dicing of the individual micro-packages

Several package configurations were fabricated in order to study the influence of the cavity and sealing ring dimensions on the hermeticity. We designed cavities with three different internal volumes: 5 mm^3, 10 mm^3 and 20 mm^3 and we tested two different widths for the sealing rings: 100 µm and 300 µm. All the packages had a lid thickness of 100 µm, a

depth of 350 µm and a substrate thickness of 450 µm. They all had a BCB sealing ring with a thickness of 7 µm. You can see in Fig. 6 the dimensions of the 5 mm^3 test vehicles with a BCB sealing ring width of 100 µm.

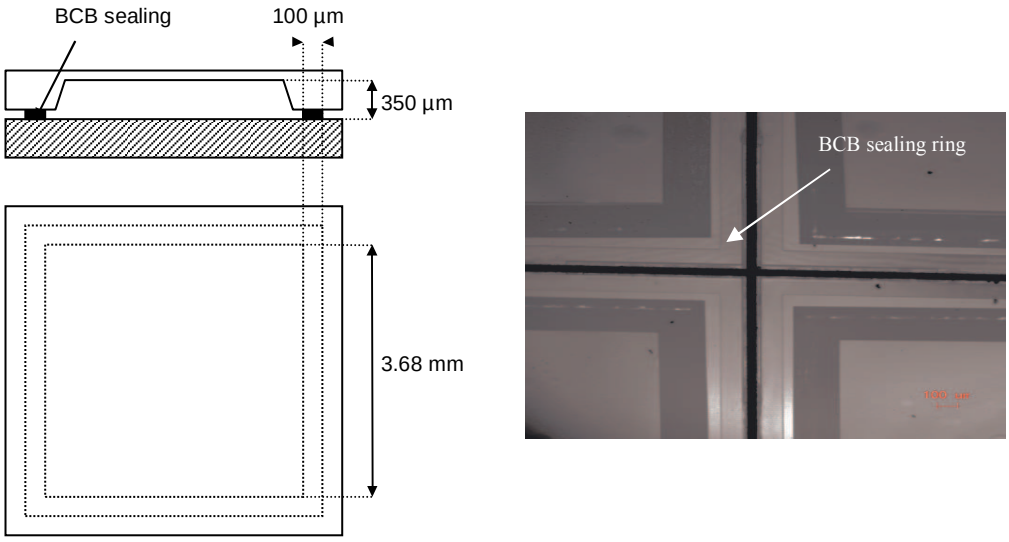

Fig. 6. Structure of a 5 mm^3 test vehicle and observation of the BCB sealing rings by IR microscopy

We tested all possible configurations of internal volume and sealing ring width. Four samples were tested for each configuration. These test vehicles were used both to validate the Fourier transform infrared spectroscopy measurement technique for the hermeticity assessment of MEMS micro-packages, and to study the influence of the sealing ring dimensions on the hermeticity of organically sealed micro-cavities.

Experimental Results

Infrared spectroscopy measurements were performed using a Nicolet ESP560 FTIR spectrometer. Infrared spectra were first plotted in transmission through the empty micro-packages, and then the test vehicles were exposed to 1.5 bar of nitrous oxide during 27 hours. Infrared transmission spectra were plotted again between 15 and 30 min after the end of the gas exposure. Dividing these spectra by the background spectra plotted for the empty packages, we obtained directly the infrared transmission spectra of the nitrous oxide contained in the tested micro-cavities.

As mentioned before, silicon is transparent to infrared wavelengths. Consequently, the hermeticity assessment of classical BCB-sealed test vehicles should present no difficulty [6]. Fig. 7 and Fig. 8 show the spectra obtained for a 20 mm^3 micro-package before and after the nitrous oxide exposure.

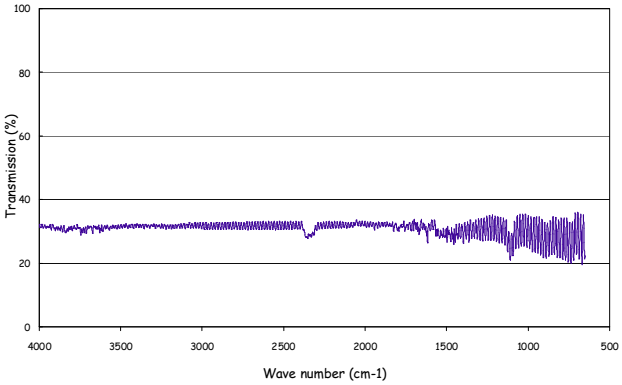

Fig. 7. IR spectrum of an empty 20 mm^3 silicon micro-package

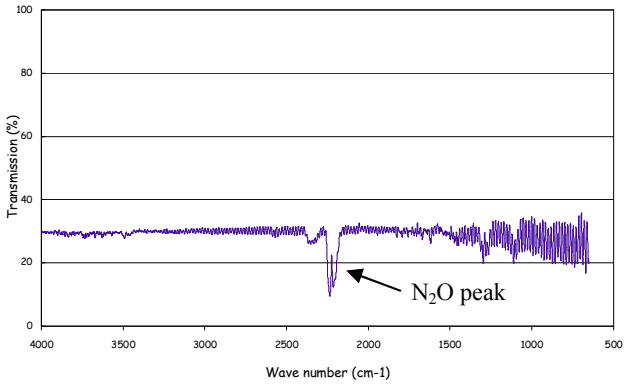

Fig. 8. IR spectrum of a 20 mm^3 silicon micro-package after the N_2O exposure

The two spectra are similar, with an additional absorption peak for the spectrum plotted after the gas exposure. This absorption peak observed for the 2240 cm^{-1} wave number corresponds to the N_2O main absorption peak. Dividing the spectrum of Fig. 8 by the spectrum of Fig. 7, we obtain directly the IR transmission spectrum of N_2O contained in the package (Fig. 9). This spectrum is very similar to the nitrous oxide absorption spectrum presented in Fig. 1. The size of the 2240 cm^{-1} absorption peak is proportional to the N_2O internal partial pressure (Eq. 2). In this paper, we will not calculate partial pressure values from the obtained spectra due to a lack of knowledge concerning the N_2O molar absorption coefficient. Calculations were carried out using coefficients found on the literature, but they need to be confirmed. Experiments are on going to determine this parameter.

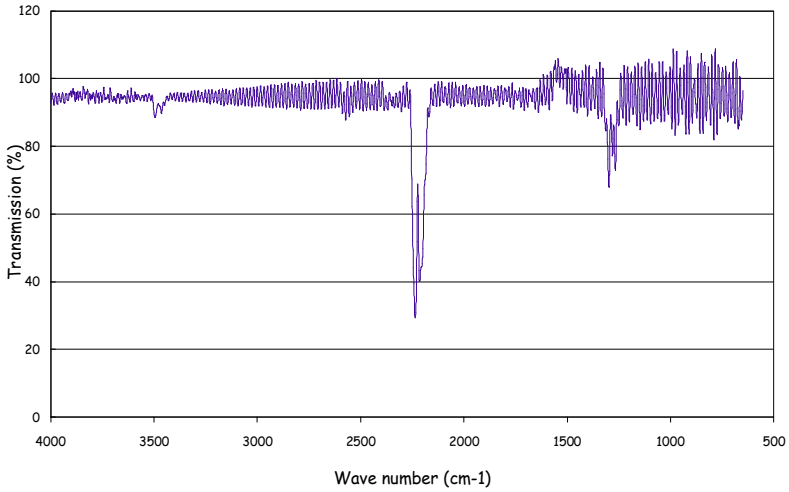

Fig. 9. IR transmission spectrum of N_2O contained in the package

Similar spectra were obtained for the other tested samples with different transmission rates for the N_2O absorption peak, depending on the dimensions of the packages. For all the tested samples except for one 5 mm^3 micro-package, we observed a significant absorption peak for the 2240 cm^{-1} wave number. It means that for all these packages, we detected the presence of nitrous oxide in the cavity. The measured transmission rates are presented in table 1.

Table 1. Measured IR transmission rates for the N_2O absorption peak (2240 cm^{-1})

Volume of the cavity		20 mm^3	20 mm^3	10 mm^3	10 mm^3	5 mm^3	5 mm^3
Width of the sealing ring		100 µm	300 µm	100 µm	300 µm	100 µm	300 µm
Measured transmission rate for the N_2O absorption peak	Sample #1	0.31	0.55	0.39	0.49	0.28	0.47
	Sample #2	0.42	0.56	0.46	0.49	0.27	0.46
	Sample #3	0.35	0.65	0.42	0.50	0.29	0.48
	Sample #4	0.36	0.53	0.33	0.46	0.30	gross leak
	average	0.36	0.57	0.40	0.49	0.29	0.57

These results confirm the non hermeticity of the BCB sealing rings. For each configuration of volume and BCB width we obtain similar transmission rates for the different samples, with small variations. If we look at the average values, there is no obvious relation between the measured transmission rates for the different internal volumes. Due to the larger contact surface between their BCB sealing ring and the external atmosphere, the 20 mm^3 micro-packages are less hermetic. But this lack of hermeticity seems to be compensated by their larger volume. So finally, there is no significant difference between the measured internal gas concentrations. On the other hand, for a given internal volume, we can observe an increase of the measured transmission rate with the increase of the BCB width. This increase of the transmission rate corresponds to a decrease of the absorption peak, and consequently to a decrease of the internal gas concentration according to the Beer-Lambert's law. This observation is coherent with the diffusion laws [7]. It means that the hermeticity of organically sealed micro-packages increases with the width of the sealing ring.

The sample with no trace of nitrous oxide inside the cavity after bombing was analyzed more in detail. Using infrared microscopy, we observed a lack of BCB at one corner of the sealing ring (Fig. 10). Consequently, this package presented gross leaks and all the N_2O had left the cavity between the gas exposure and the IR measurement.

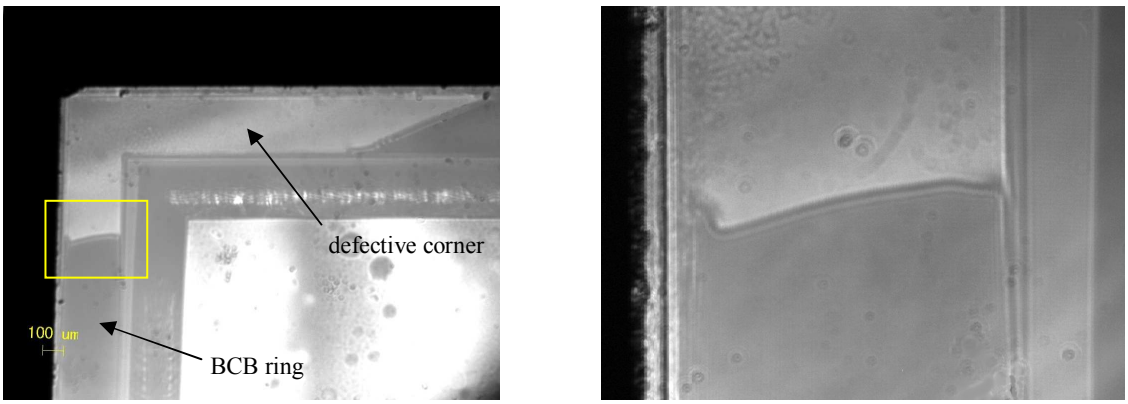

Fig. 10. Infrared spectroscopy observation of the defective BCB ring

CONCLUSION

Fourier transform infrared spectroscopy can be applied to the hermeticity assessment of MEMS micro-packages. The performed experiments using N_2O as a tracer gas confirm its interest for the hermeticity assessment of silicon micro-cavities with organic adhesive sealing rings. They prove that it is possible to detect the presence and the pressure variation of a tracer gas in such a package. FTIR spectroscopy was applied to BCB-sealed micro-packages to study the influence of different parameters on their hermeticity properties. We did not find any obvious link between the size of the tested packages and their hermeticity, but we clearly demonstrated an influence of the width of the sealing ring on the hermeticity of BCB-sealed micro-cavities.

This promising hermeticity assessment method will now be improved in order to develop an alternative to classical techniques such as helium leak detection. Further investigations will be led on the internal gas pressure quantification, to obtain accurate leak rate values and thus to carry out concrete measurements of the hermeticity of the micro-packages. The technique will also be tested on smaller packages, with internal volumes of 1 mm^3 or less, in order to validate the model on actual cavities used for the wafer level packaging of MEMS devices.

ACKNOWLEDGEMENTS

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