Shortening of Evaluation Time by Highly Accelerated Stress Test and Improvement of Analysis Technique for Passivation Film

Authors: *Koichi Inoue** and *Hajime Sasaki**

1. Introduction

Optical semiconductor devices are often put in hermetic packages to prevent the characteristics from changing depending on the temperature and humidity of the environment. However, because more devices have been used without hermetic packages in recent years for some applications, it has been become essential to secure and verify the humidity robustness of the devices themselves. As reliability standards for optical semiconductor devices, Telcordia GR-468-CORE issue 2[1] is often used. A high temperature and high humidity test under temperature and humidity conditions conforming to the standards (85°C/85%RH) takes several thousand hours, which can cause problems for product development schedules. In order to study changes in characteristics that occur in products on the market, this test time needs to be reduced. In evaluating the humidity robustness of optical semiconductor devices under development, we studied whether highly accelerated stress tests could be applied, and report the results here.

2. Application of HAST Conditions and Acceleration

We considered applying highly accelerated stress tests (HAST) as further accelerated tests in place of high temperature and high humidity tests at 85°C/85%RH conforming to the specifications of Telcordia GR-468-CORE issue 2. When HAST is introduced, it is important to note that if a phenomenon different from the change mechanism in the original service environment appears, the test is not regarded as an accelerated test.

As the temperature and humidity conditions of this HAST, the temperatures were determined as 115°C and 130°C (two conditions) and the humidity was determined as 85%RH (single condition). Table 1 lists the absolute water vapor pressure for the temperature and humidity environments. The table shows that the higher the temperature is, the higher the absolute water vapor pressure is.

Figure 1 is a schematic diagram of a HAST chamber. The steam generated by heating the water is further heated; a fan is used for mixing and a valve is used to adjust the pressure to create a high temperature and high humidity environment in the single-chamber tester used. Figure 2 is a graph showing the duration of the high temperature and high humidity test until the

Table 1 Absolute water vapor pressure versus high temperature and high humidity conditions

Temperature and humidity conditions	Absolute water vapor pressure (kPa)
55°C/85%RH	13.3
65°C/85%RH	21.3
85°C/85%RH	49.1
115°C/85%RH	143.0
130°C/85%RH	229.0

Conventional conditions

HAST conditions

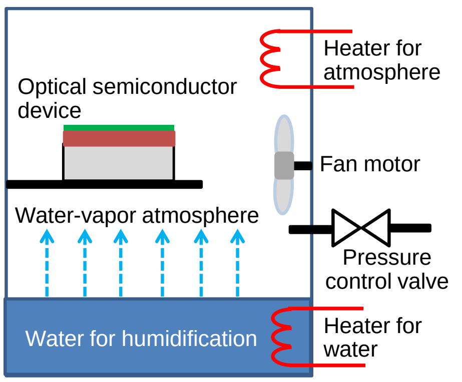

Fig. 1 Schematic drawing of HAST chamber

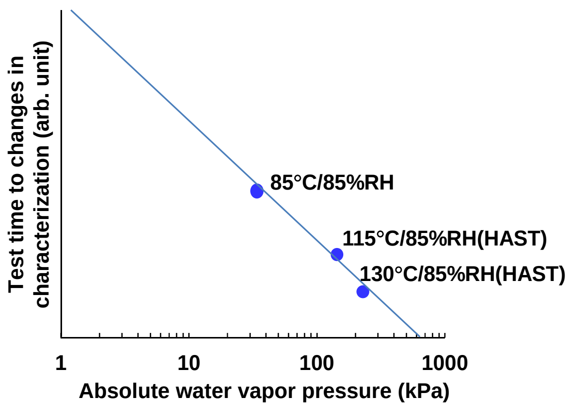

Fig. 2 Duration of high temperature and high humidity test for changes in characteristics versus absolute water vapor pressure

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characteristics of the optical semiconductor devices changed to the absolute water vapor pressure. The evaluation was made for a total of three conditions including the results of a test at 85°C/85%RH conforming to Telcordia GR-468-CORE issue 2. As a result, when the test time until the characteristics changed was plotted against a power of the absolute water vapor pressure, a correlation was found.

3. Analysis Techniques Used after the Test and Analysis Results

3.1 Analysis techniques used after the test

The results of the high temperature and high humidity test indicate that under the HAST conditions, acceleration was obtained. In order to judge whether the result is appropriate, the optical semiconductor device before and after the test needs to be analyzed to confirm that the change mechanism is the same as that under conventional test conditions.

The results of reliability tests obtained in the past show that changes in moisture absorption by silicon nitride films, which are used to protect the surfaces of optical semiconductor devices, cause deterioration. Accordingly, we focused on the silicon nitride film for comparison. As the check methods, a scanning transmission electron microscope (STEM) was used for observation, and energy dispersive X-ray spectroscopy (EDX) and electron energy loss spectroscopy (EELS) were used to analyze the composition and evaluate the chemical bonding state. Figure 3 illustrates the configuration of the measurement system consisting of STEM, EDX, and EELS.

3.2 Analysis by STEM, EDX, and EELS

The silicon nitride film before and after the high temperature and high humidity test was observed with STEM and analyzed by EDX mapping, and the results were compared. Figure 4 shows the oxygen (element) mapping results. The figure shows that on the surface of the silicon nitride film on the top layer of the optical semiconductor device, the contrast in the STEM images after the tests is different from that before the test and oxygen was detected on the sections.

The EDX analysis results clearly show that oxygen exists on the surface of the silicon nitride film after the high temperature and high humidity test. In order to inspect the composition and chemical bonding state at the section more closely, EELS analysis was performed. Figure 5 shows an enlarged STEM image of the silicon nitride film after the high temperature and high humidity test (130°C/85%RH) along with points analyzed by EELS. Figure 6 shows the STEM-EELS spectra by point analysis. The analyzed points were points 1 and 2 in Fig. 5. At point 2, which is located more than 4 nm inside from the surface, there is silicon nitride.[2][3] Near 106 eV, there is a peak due to absorption by the L2 and L3 shells and near 160 eV, there is a peak due to absorption by the L1 shell. 106 eV is by the Si-N bond. On the other hand, at point 1, which is located approximately 2 to 3 nm from the surface, there is silicon oxide.[2][3] Near 108 eV and 116 eV, there are peaks by absorption by the L2 and L3 shells and near 160 eV, there is a peak by absorption by the L1 shell. These results show that the area approximately 2 to 3 nm from the surface of the silicon nitride film reacted with oxygen to form silicon oxide and volume expansion occurred; as a result, the stress applied to the optical semiconductor device

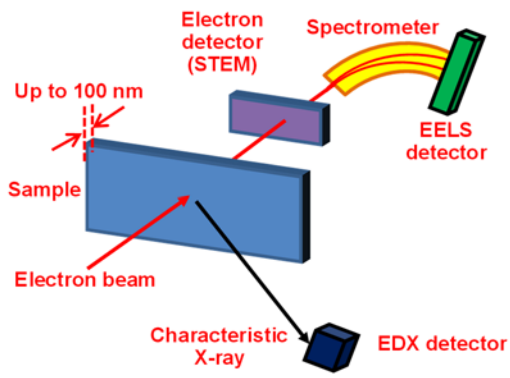


Fig. 3 Configuration of STEM, EDX and EELS

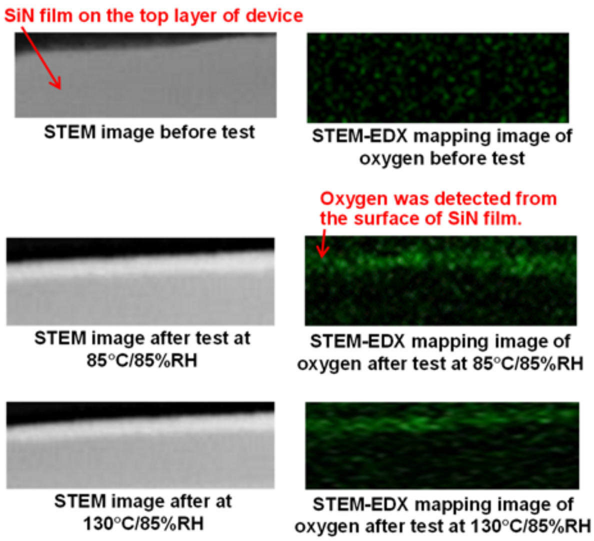


Fig. 4 STEM images and oxygen mappings by EDX

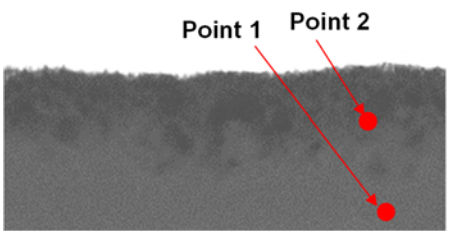
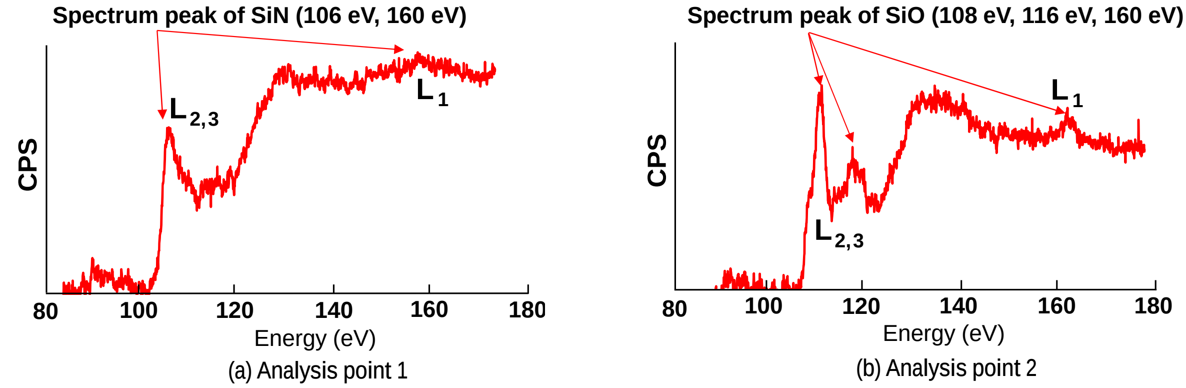


Fig. 5 EELS analysis points on silicon nitride film after test at 130°C/85%RH



CPS: Count Per Second

Fig. 6 EELS energy spectrum on silicon nitride film after test at 130°C/85%RH

changed, which caused the changes in characteristics. These changes were the same for the high temperature and high humidity tests at 130°C/85%RH (HAST conditions) and at 85°C/85%RH.

These results show that highly accelerated stress tests can be applied. This will greatly contribute to verifying the humidity robustness of products under development more efficiently in the future.

4. Conclusion

We studied whether highly accelerated stress tests could be used to evaluate the humidity robustness of optical semiconductor devices under development. The results showed that the change mechanism of the optical semiconductor devices is the same between the high temperature and high humidity tests at 130°C/85%RH and at 85°C/85%RH conforming to Telcordia GR-468-CORE issue 2. This finding demonstrates that the highly accelerated stress test can be applied as an appropriate test procedure. Reducing the duration of the high temperature and high humidity test using these conditions will shorten the time required for reliability tests in product development.

References

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