Thailand-Japan MicroWave 2016

GaN Diode Measurement for Rectifier Design at 5.8 GHz

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Abstract This paper reports the impedance measurement of a gallium nitride shottky diode at 5.8 GHz. To correct the effects of the end-launch connectors and the lines in the measurement system, open, short, and load lines were manufactured. And we characterized the effects of the wires connecting the diode and the line. Impedance of the GaN schottky diode removed the effects of the measurement jigs was 5.5-*j*18.2 Ω at 5.8 GHz. Imaginary part of impedance before removing the wire effects was positive value. So, the wire characterization is essential for the measurement configuration.

Keyword gallium nitride, diodes, wireless power transmission, impedance, measurement, modeling

1. INTRODUCTION

Gallium nitride (GaN) is an attractive material in semiconductor technology. It has the splendid properties of high temperature operation, high frequency operation, and high resistivity to cosmic rays, etc. So, much research and development have been advanced all over the world [1][2]. We are developing a rectifier and an amplifier using GaN devices to construct wireless communication systems and wireless power transmission systems for space crafts. The operating frequency is 5.8 GHz.

In order to make the most use of the advantages of GaN and design a rectifier using GaN shottky diode with efficiency, it is essential to characterize the property. The property is generally estimated from measurement results or theoretical analysis. But theoretical device characterization without measurements is difficult. It is because process capable of calculation is not clear for an actual diode and amount of calculation is large in many cases. We select the method based on measurement results.

The ultimate goal of our rectifier is to fuse Si base analog-digital integrated circuit and compound monolithic microwave integrated circuit (MMIC) called hybrid semiconductor integrated circuit (HySIC). The advantage is that development cost is low and integration of many functions is easy on one chip. And system becomes small and light, so it is useful in space crafts.

In this paper, we will report the impedance measurement of a GaN schottky diode at the frequency of 5.8 GHz. In the second section, the lines for calibration will be introduced. Measurement and analysis based on the calibration lines will be reported in the third section. And the last section will be conclusion of the paper.

2. CALIBRATION

For measuring impedance of GaN shottky diode mounted on a printed circuit board, we made calibration lines based on open-short-load method [3].

The base line structure was coplanar line without rear conductor. Coplanar structure is advantageous compared with microstrip structure. For coplanar structure, via holes are not needed to connect to the ground, so manufacturing of the lines are easier.

2.1. OPEN AND SHORT LINE

The schematic view of the open line is shown in Fig. 1 and Fig. 2 (a). The difference between the line and ground at the end of the line was 1 mm. At the frequency of 5.8 GHz, magnitude and phase of reflection coefficient seen from the connector mating plane Γc were 0.965 and -160.70 °, respectively. The measurement instrument was a vector network analyzer and the input power was -0.24 dBm.

The structure of the short line was shown in Fig. 1 and Fig. 2 (b). Magnitude and phase of reflection coefficient from the connector mating plane Γc was 0.956 and 19.29 °, respectively. The measurement condition was the same as the open line measurement.

The differences between Γc of the open line and the short line were 0.009 in magnitude and 179.99 ° in phase at 5.8 GHz. An ideal open and short line

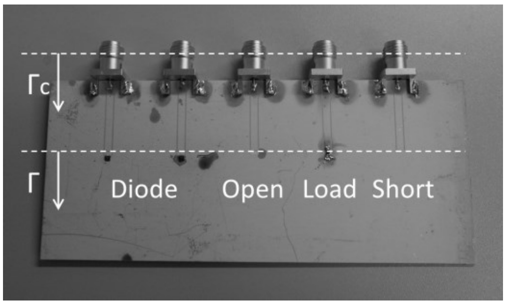

Fig. 1. Photograph of the open, short, load, and diode mounted lines. Reflection coefficient seen from the connector mating planes and from the end of the line were defined as Γc and Γ, respectively.

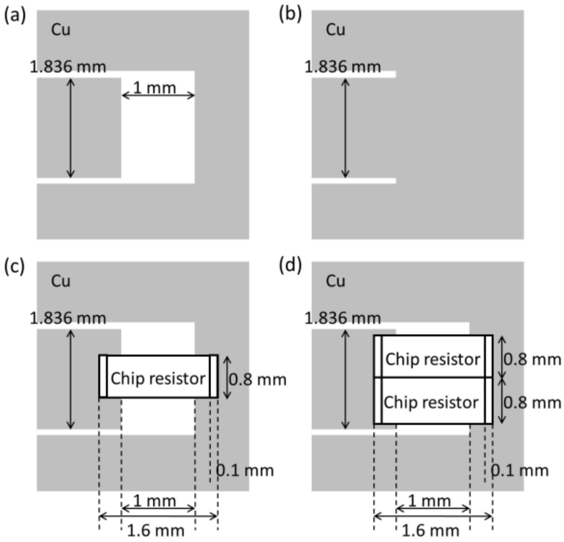

Fig. 2. The schematic views of the calibration lines. The open (a), the short (b), the load (c)(d) lines.

TABLE I. Definition of the load lines

Name	**Resistance**	**Mount**
Load I	One chip resistor Typical 47 Ω	Fig. 2 (c)
Load II	One chip resistor Typical 51 Ω	Fig. 2 (c)
Load III	Two chip resistors Typical 100 Ω	Fig. 2 (d)

have phase difference of 180 °, so we considered that the lines were available.

2.2. LOAD LINE

Reflection coefficient of a load line mostly depends on method of mounting chip resistors. We manufactured three types of prototypes and measured reflection coefficient Γc.

Each mounting method is shown in Fig. 2 (c), (d), and Table I. For Load I, one chip resistor was mounted between the end of the line and the ground using solder. The typical resistivity of the chip resistor was 47 Ω. The structure of Load II was same as Load I. But the typical resistivity was 51 Ω. It was because there were not typical 50 Ω chip resistors in the series. Typical 47 Ω and 51 Ω resistors were the closest values to 50 Ω. For Load III, two chip resistor were mounted in parallel between the end of line and the ground. The typical resistive values were 100 Ω. All chip resistor were made by the same manufacturer and had the same series number.

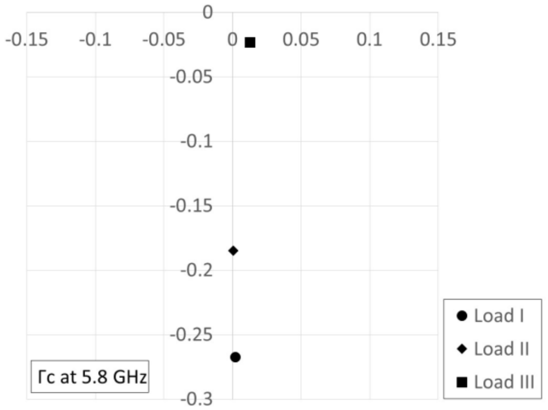

Fig. 3. Measured reflection coefficient seen from the connector plane Γc for load lines at 5.8 GHz.

Measured reflection coefficient of the load lines at 5.8 GHz are shown in Fig. 3. They were reflection coefficients seen from the connector mating planes Γc. A vector network analyzer was used and the input power was -0.24 dBm. Each magnitude of Γc of Load I, Load II, and Load III was 0.27, 0.18, and 0.027, respectively.

Measured reflection coefficient Γc of Load I and Load II whose mounting structure were based on Fig. 2 (c) were bigger than calculated. Based on theoretical calculation, reflection coefficient of Load I and Load II are 0.031 and 0.0099, respectively. The soldering process and the difference of chip resistor width and the line width are considered to give serious effect to reflection of the lines at 5.8 GHz.

At 5.8 GHz Load III was the best among the three load lines, because an ideal load line has zero reflection. In mounting chip resistors, it is important that a width of transmission line is close to a width of the mounted resistors.

3. MEASUREMENT OF DIODE

At 5.8 GHz we measured reflection coefficient of a GaN schottky diode. And based on the open, short, and load lines mentioned in the previous section, the effects of jigs were removed from the measured reflection coefficient Γc. The input power was -0.24 dBm.

3.1. VECTOR NETWORK ANALYZER MEASUREMENT

A GaN shottky diode was mounted at the end of

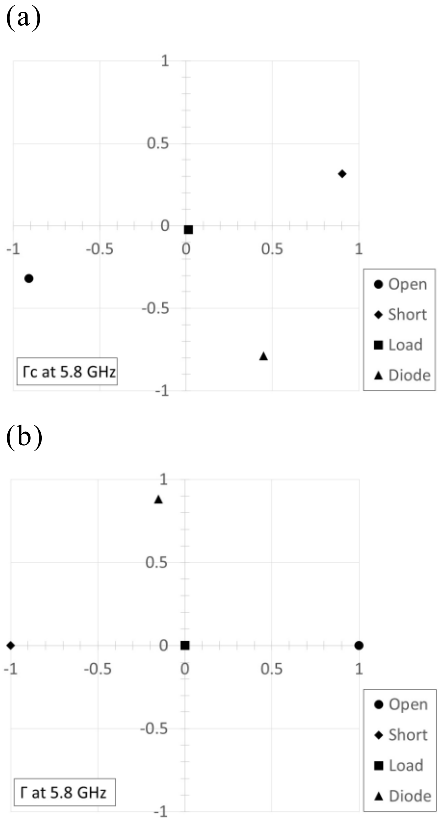

Fig. 4. Measured reflection coefficient Γc (a) and corrected reflection coefficient Γ (b) of the open, short, load, and diode lines at 5.8 GHz.

the line. The schematic drawing is shown in Fig. 5 (a). The anode electrode of the diode was connected to the line with 4 Au wires and the cathode electrode was connected to Cu plate with conductive paste. The difference between the end of the line and the Cu plate was 1 mm.

Measured reflection coefficient seen from the connector mating planes Γc at 5.8 GHz are shown in Fig. 4 (a). Measurement instrument were a vector network analyzer and the input power was -0.24 dBm.

3.2. CORRECTION OF CONNECTOR AND LINE

To remove effects of the end-launch connectors and the coplanar line and to estimate impedance of the diode seen from the end of the line Γ, we analyzed the measured reflection coefficient Γc using the open, short, and load lines. The correction equation between measured reflection coefficient Γc and reflection coefficient of device Γ is

$$\Gamma_C = e_{00} + \frac{e_{10}e_{01}\Gamma}{1-e_{11}\Gamma} \qquad (1)$$

Here, *e*ij (i, j=0, 1) are scattering parameters of the connectors and the lines (Fig. 6) [4][5].

Fig. 4 (b) shows the corrected reflection coefficient Γ at 5.8 GHz. First, we considered reflection coefficient Γ of the open, short, and load lines as 1, -1, and 0, respectively. Then scattering parameters *e*ij were calculated from Γc and Γ of the

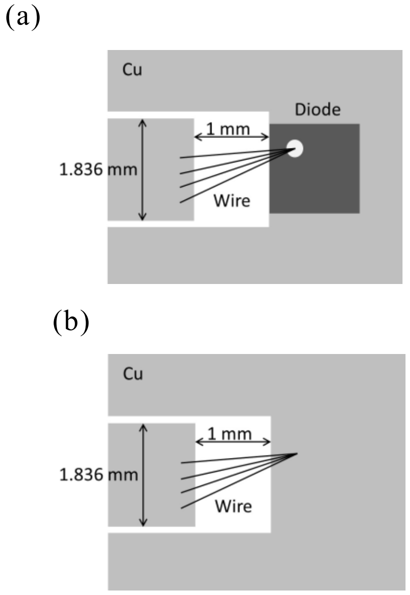

Fig. 5. The schematic views of the GaN shottky diode mounted at the end of the line (a). The schematic view of the line for wire characterization (b).

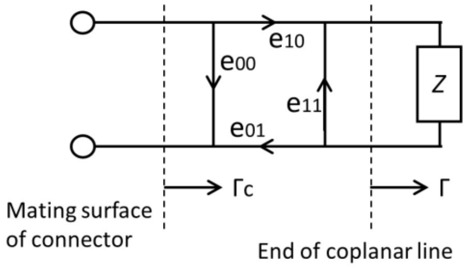

Fig. 6. Model of the end-launch connectors and the coplanar lines.

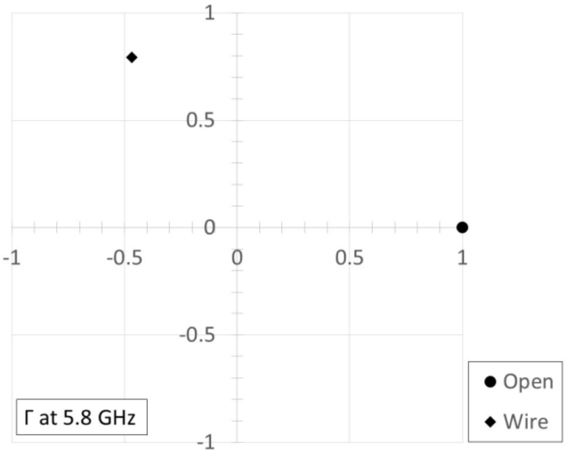

Fig. 7. Reflection coefficient Γ of the open line (Fig. 2 (a)) and the wired line (Fig. 5 (b)) at 5.8 GHz.

open, short, and load lines. Finally, using the scattering parameters *e*ij, reflection coefficient of the GaN shottky diode Γ was estimated.

Impedance of the GaN shottky diode *Z* was equal to 4.7+j41.9 Ω at 5.8 GHz. The value was calculated from Γ using the following complex equation

$$Z = 50\frac{1+\Gamma}{1-\Gamma} \tag{2}$$

The value includes the effect of the wires, soldering, and connection to the ground.

3.3. CORRECTION OF WIRE

The effects of the wires connecting the coplanar line and the diode were estimated. First we measured an open line. Then 4 Au wires were bonded on the open line like the similar shape of the diode mounted line (Fig. 5 (b)) and we measured it. The corrected reflection coefficients Γ of the open and wired line at 5.8 GHz were shown in Fig. 7. The ratio in magnitude of Γ was 0.92 and the difference in phase of Γ was 239 °.

Using the two values, the calculated impedance which was removed the wire effects from 4.7+j41.9 Ω was 5.5-j18.2 Ω. Imaginary part of the impedance became capacitive after removing the wire effects. Because imaginary part of impedance for general diode models is negative, removing the wire effect was essential.

If a general equivalent circuit model which is parallel of a capacitance C and a resistance R [6] is applied to 5.5-j18.2 Ω, C is approximately 1 pF.

4. CONCLUSION

We measured impedance of a GaN schottky diode at the frequency of 5.8 GHz. To ensure the reliability of the measurement results, the two correction method were performed. One is the correction of the connectors and the lines by the open-short-load lines and the other is the correction of the wires by the wire characterization line.

The first conclusion is that characteristics of load lines strongly depends on mounting method. To manufacture low reflection load, it is better that the width of the line is close to the width of the mounted resistors.

The second conclusion is that impedance removed the effects of the end-launch connectors, the lines, and the wires was 5.5-j18.2 Ω at 5.8 GHz. We confirmed that the correction factors shifted measured raw data largely. The correction is essential for the measurement configulation.

Accomplishing a diode model is our next study. We will design a high efficiency rectifier based on the diode model.

Acknowledgement

This work is supported by Japan Space Systems (JSS), Ministry of Economy, Trade and Industry (METI). We would like to thank Mr. Okada and Mr. Ueno from Sumitomo Electric Industries, Ltd. and Mr. Nakatsuka and Mr. Anma from Mitsubishi Heavy Industries, Ltd.

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