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Characteristics of RF-DC Conversion Circuit for Wireless Power Transmission using the Low Resistance GaN Schottky Barrier Diode

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Abstract— **RF-DC conversion circuit is one of the most important components in the wireless power transmission technologies. For realizing highly efficient wireless power transmission, it is necessary to design the RF-DC conversion circuit with high conversion efficiency, and the designing method of the circuit is actively investigating. In this paper, we manufacture the GaN schottky barrier diode for a high frequency rectification, and discuss characteristics of the GaN circuit by comparing to the Si circuit. As a result, optimal electrical parameters of the diode are demonstrated for obtaining higher conversion efficiency in the RF-DC conversion circuit.**

I. INTRODUCTION

Recently years, microwave and millimetre-wave are used for the wireless power transmission. For example, Space Solar Power System[1], Radio Frequency IDentification, charging system to electric vehicle[2][3], etc.. For realizing an efficient wireless power transmission system, the RF-DC conversion circuits must be highly efficient circuit. In general, a diode which has low build-in voltage is selected to satisfy this requirement, however its breakdown voltage becomes smaller in such diode, simultaneously. The diode which has low built-in voltage and high breakdown voltage is expected because the reverse bias is always imposed to the RF-DC conversion circuit under its operation. In our past report, we designed the RF-DC conversion circuits by using the Lumped Element Finite Difference Time Domain(LE-FDTD) method[4]. We investigated not only characteristics of the RF-DC conversion circuit, but also influences of equivalent circuit parameters of the diode[5]. In this paper, we investigate influences of equivalent circuit parameters of the Si schottky barrier diode and discuss optimal parameters for obtaining higher conversion efficiency. Moreover, we manufacture the GaN schottky barrier diode for high frequency rectification based on our obtained finding and discuss characteristics of the RF-DC conversion circuit by using this GaN diode.

II. RF-DC CONVERSION CIRCUIT AT 5.8GHZ

The rectenna is composed of the receiving antenna, the matching circuit, the rectification diode, the output filter, and the load resistance. Microwave is received with the antenna, and rectified by the diode. Only generated DC power is led to the load resistance because AC powers are prevented from leaking to the load resistance by the band stop filter or the low pass filter.

For higher efficient rectification, the voltage imposed between the anode and the cathode terminals of the diode is very important. In our circuit, the cathode terminal is grounded at the input frequency and its harmonic frequencies. Then, the connected position and its length of the short stub is adjusted to impose higher voltage to the anode terminal. The configuration of RF-DC conversion circuit at 5.8GHz is shown in Fig.1.

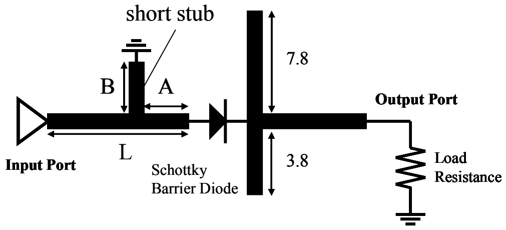


Figure 1: The configuration of RF-DC conversion circuit at 5.8GHz.

The dielectric substrate thickness is 0.5mm and the relative permittivity is 3.4. The characteristic impedance of the microstrip line is 50ohm at 5.8GHz. A, B and L are length between the anode terminal and the short stub, length of the short stub and length between the input port to the anode terminal, respectively. Their parameters are indicated by the ratio of wavelength. The Si schottky barrier diode(Avago HSMS-282B) is chosen. The conversion efficiency depended on the load resistance and the input microwave power. Therefore, when the input power and the load resistance are changed, A, B and L are also changed for obtaining a highest conversion efficiency under its input and output conditions. In Fig.2, optimum structural parameters corresponding to the input power and the load resistance are shown in (a), (b) and (c), and maximum conversion efficiencies corresponding to optimal structural parameters are shown in (d). In each maps, the horizontal and the vertical axis are the input power and the load resistance, respectively.

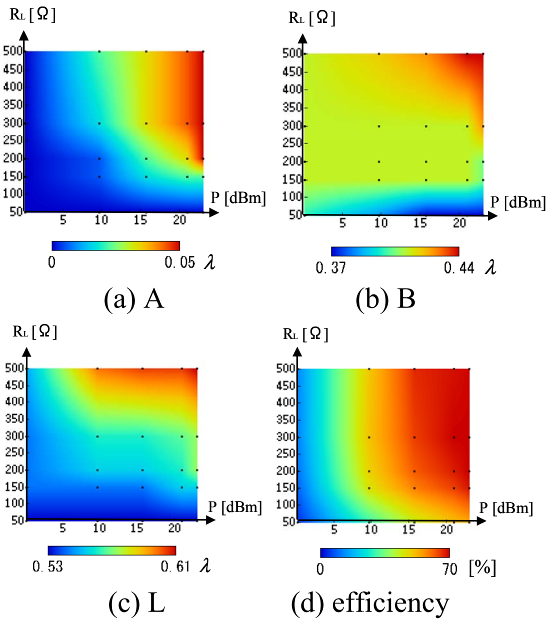
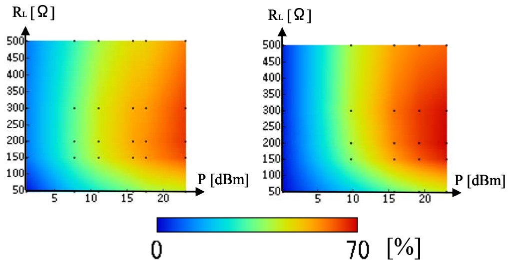


Figure 2: Parameters and the conversion efficiency of structure of maximum conversion efficiency in each input power and load resistance.

In Fig. 2(d), maximum conversion efficiencies become higher as the input power grows, though they slightly change as the load resistance grows. On the other hand, optimal structural parameters change according to both input power and load resistance.

Fig. 3 shows the conversion efficiency obtained by the simulation and measurement when structural parameters are fixed to values for obtaining highest conversion efficiency shown in Fig. 2(d). The highest conversion efficiency is 69.1% when the input power and the load resistance are 23.1dBm and 200Ω, respectively. At this time, A, B and L as structure parameters are 1.7mm, 12.3mm and 18.2mm, respectively.



(a) Simulation (b) Measurement

Figure 3: RF-DC conversion efficiency according to the load resistance and the input microwave power.

In these results, it is confirmed that the measurement result is agree well with the simulation result and the region size of high efficiency decreases to compare with Fig. 2(d) because the circuit structure is fixed. In measurements shown in Fig. 3(b), the maximum conversion efficiency is 64.6%.

III. INFLUENCES OF DIODE PARAMETERS ON THE CONVERSION EFFICIENCY OF RF-DC CONVERSION CIRCUIT

Next, the influence of electrical parameters of the diode is investigated. Fig. 4 shows the equivalent circuit of the diode integrated in our simulation.

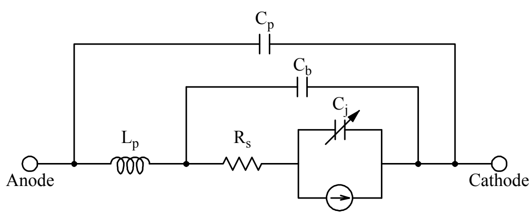


Figure 4: The equivalent circuit of diode.

Table 1: Equivalent circuit parameters of diode(HSMS282B)

Parameters	value	Unit
IS	2.17E-08	A
N	1.48	
BV	17.93	V
Rs	7.92	Ω
Vj	0.3	V
M	0.6058	
Cj(0)	3.90E-13	F
Lp	9.21E-10	H
Cb	3.85E-13	F
Cp	-	F

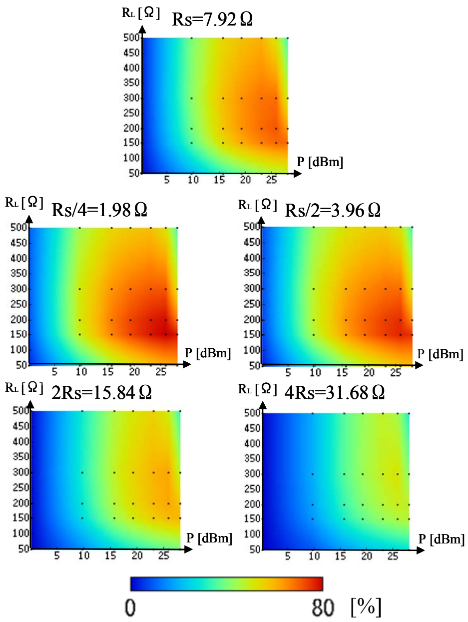


Figure 5: Conversion efficiencies when the contact resistance of diode is varied.

Rs, Cj, Lp, Cb, and Cp shown in Fig. 4 are the contact resistance, the junction capacitance, the parasitic inductance, the parasitic capacitances, respectively. These equivalent circuit parameters are obtained by the static characteristic measurement and the input impedance measurement. The SPICE diode model is adopted as non-linear function of the current source. The fitting parameter of diode(Avago HSMS-282B) is indicated in Tab. 1.

First of all, the influence of Rs is investigated. In simulations, conversion efficiencies corresponding to Rs/4, Rs/2, 2Rs and 4Rs are shown in Fig. 6. At this time, Rs means same value shown in Tab. 1. Structural parameters are adjusted to optimum whenever diode parameters are changed.

In Fig. 5, it is confirmed that conversion efficiencies become higher as R_S becomes smaller. The maximum conversion efficiency is 79.9% when Rs is adjusted to 1/4. Therefore, it is understood that the influence of the contact resistance appears simply as a loss.

Next, the influence of the junction capacitance Cj is also investigated. As same in the case of R_S, conversion efficiencies corresponding to Cj/4, Cj/2, 2Cj, and 4Cj are shown in Fig. 6.

The conversion efficiency becomes higher as Cj becomes smaller in Fig. 6, and the maximum conversion efficiency is 74.28%. This is because the impedance of C_j branch becomes larger, and microwave reverse current is difficult to flow. Fig. 7 shows simulated results that indicates this phenomenon. Here, a red and a black solid lines mean the current that flows to R_S in the case of Cj/4 and 4Cj, respectively.

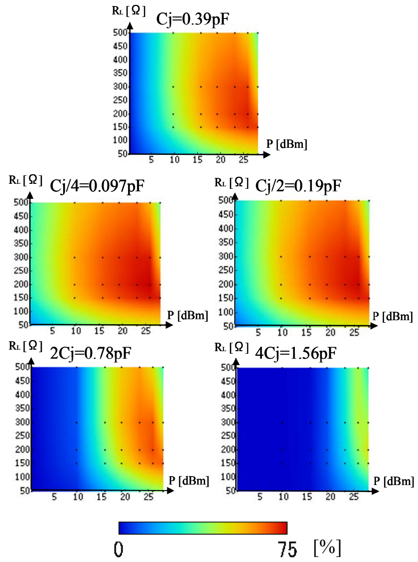


Figure 6: Conversion efficiencies when the junction capacitance of diode is varied.

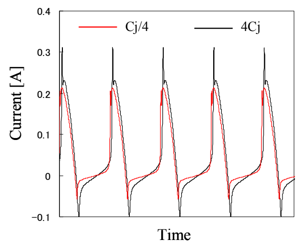


Figure 7: A comparison of the current waveform flowed at Cj when junction capacitances are 4Cj and Cj/4.

Though it is confirmed that a large reverse current flows in the case of 4Cj, the reverse current becomes small in the case of Cj/4.

IV. THE CHRCTERISTIC OF THE RF-DC CONVERSION CIRCUIT USING THE GAN DIODE

In this study, the GaN schottky barrier diode for microwave rectification has been manufactured. The fitting parameter of GaN diode is indicated in Tab.2. This GaN diode has low resistance shown in Tab. 2. About other diode parameters, the parasitic reactance is reduced by using small package and short bonding wires. The breakdown voltage is also larger than one of the Si diode due to the physical property of GaN. The junction capacitance is unfortunately larger due to the reduction of R_S.

Table 2: Equivalent circuit parameters of diode(GaN)

Parameters	value	Unit
IS	3.82E-13	A
N	1.15	
BV	1.23	V
Rs	33.13	Ω
Vj	0.7174	V
M	0.4174	
Cj(0)	1.72E-12	F
Lp	3.63E-13	H
Cb	-	F
Cp	-	F

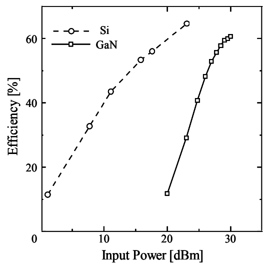


Figure 8: The comparison of the conversion efficiency of the RF-DC conversion circuits by using two diodes.

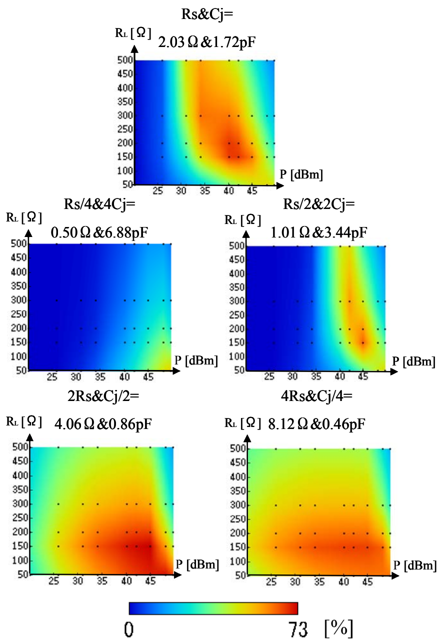


Figure 9: Conversion efficiencies when the contact resistance and the junction capacitance of GaN diode is simultaneously varied.

The measured conversion efficiency of the RF-DC conversion circuit by using the GaN diode is shown in Fig. 8. In this figure, the conversion efficiency by using the Si diode is also indicated.

The RF-DC conversion circuit by using the GaN diode is operated at higher input power than the Si diode, and maximum conversion efficiency is 60.7% within the range that can be measured. This is understood that the reverse current becomes large caused by an increase in the junction capacitance though its contact resistance is suppressed. Fig. 9 shows simulated conversion efficiencies when Rs and Cj are changed simultaneously with keeping its cut off frequency. In these results, the maximum conversion efficiency is 72.45% in the case of 2Rs and Cj/2. Therefore, the influence of junction capacitance appears in the efficiency in this trial manufacture.

V. Conclusions

In this paper, we manufactured the GaN schottky diode for microwave rectification, and investigated characteristics of the RF-DC conversion circuit using it. The contact resistance of the manufactured GaN diode is small to compare with the Si diode, however highly conversion efficiency could not obtain because the reverse current becomes larger caused by an increase of the junction capacitance. As a future work, the structure of diode that the contact resistance and the junction capacitance are suppressed will be investigated for obtaining high conversion efficiency.

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