Transmission line method (TLM) measurement of low resistance Ni/Ti/Pt/Ti/Pt Au ohmic contact system to p+-type GaAs

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Tl er is used for ohmic contacts to p-type GaAs. The co ntial e-beam evaporation of 5 nm Ni, 5 nm Ti, 5 nm Pt, layers onto the 300 × 10^{19} cm^{-3}) p+-G beam epitaxy (MP ing (RTA) is per contact resistivity here at temperatu to 460°C with inter ontact resistance is $2.633 \times 10^{-5} \Omega\mathrm{cm}^2$ for this epitaxi value at RTA time of 1 minute and temperature ance differences by temperature changes was very sr

I. INTRODUCTION

Since all semiconductor devices have contacts and all contacts have cont ll contacts have contact resistance haracterize such contacts. Ir of ohmic contacts and ill be concerned ntacts because the ssion of the meas ntact is unimporta ntact material is im

Low-resistan cial in determining semi rmance in various application optoelectronic devices, bipolar transistors and microwave devices.[1]

Particularly, an ohmic contact with low-resistance not only provides a medium for injecting a current to drive a device to reach the desired performance but also a contact where device can be o urrent value without having thermore, as the devic er, low-resistance more important nance. Because o groups focused on ohmic contacts.

In this rep s of the Ni/Ti/Pt/Ti/Pt , which has low contact resist on line model (TLM) method is adopted to study the effect of the metal contact for ohmic contact.[2]

II. EXPERIMENTAL DETAILS

A. Cont

Metal-semiconductor contacts fall into two basic categories, illustrated in Fig. 1

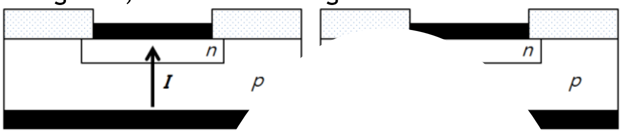

Fig. 1 (a) "Verti act

The current flo ally into the contact eral contacts can be he effective conta ue contact area.[3]

In vertical ca is given by $\rho_C =$

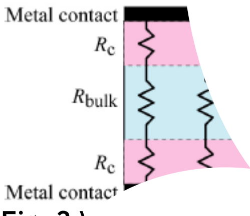

Fig. 2

H ormly through the co ted in Fig. 3

Fig. ry

The $_C$A) is not valid in this

case, so a different method is required to measure the contact resistance.[4]

B. Transmission line method[4]

A transmission lin- ted circuit elements just as sh

Fig. 4 Transmiss el

The mathema s well known in the 1970s. ssion line model was applied t contacts in semiconductors. It is intuitively clear that the current prefers to flow laterally in the metal contact rather than the semiconductor. Thus, there is a transfer length within which the current transfers from the metal to the semiconductor. The TLM model allows one to extract the specific contact resistance of a contact with lateral current flow. The following figure shows TLM measurement. TLM measurement uses a series o ifferent intervals like L_i = 2, 4, 6 10, 15, 20, and 25 um. d widths (W) are 200 u

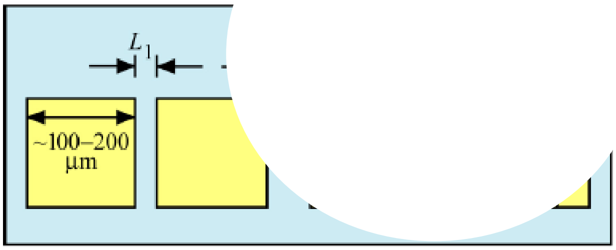

Fig. 5 Series of contact with different intervals

In other words, the TLM is applied to determine a specific contact resistance for planer ohmic contact.

The TLM measurement that we use is illustrated in Fig. 6.

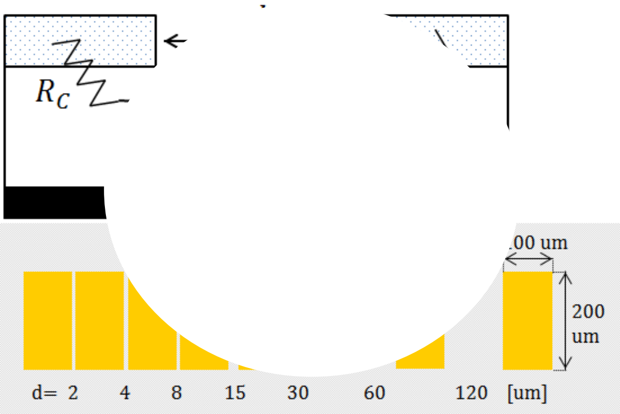

Fig. 6 Equivalent circuit and TLM metal pattern

The TLM measurement yields values for R_C and L_T. Assume that the semiconductor has the sheet resistance R_{sheet}. The TLM analysis yields the following relations:

$$R(L) = (L+2L_T)\, R_{sheet} / W,$$

$$R(L = 0) = 2 \ldots /W$$

Solving equatio nd specific contact resistan

$R_{s'}$

The poten act is such that th ntact edge and dr nce. The "1/e" d fined as the transfe

Thus the TLM n assess the specific contact re t current flow geometry. Th te contact resistances is "Transfer length meth n, TLM.

We obt y the semicondu nd the similar gra as Fig. 7 by using easured resistances a tion and the resistance

Fig. 7 Resista

We can calcu s), contact resistance (R_c), spe ance (r_c), and transfer length (L_T) by using above the equations.

C. Process of experiment.

P-type GaAs epitaxial layer doped by Beryllium (Be) is gr beam epitaxy (MBE). The dopir 4×10^{19} p+ doping. A v get convenient size t

ned with acetone nd deionized (DI) onic at a room t

thography. Coating a ph -coater is performed. It is sp . Hexamethyldisilazane (HMDS) for b adhesion is coated on samples with 3000 rpm for 20 seconds. AZ5214 positive photoresist (PR) is coated on samples with 5000 rpm for 30 seconds. For better mask alignment the edge PR is removed. Soft-baking is performed for evaporating the moisture on hot plate for 90 sec at 90℃. In PR patterning, we used a mask aligner machine with TLM pattern mask and then, exposed the sample to ultraviolet for 9 seconds. After exposure, post … for image reversal processing … as negative PR is carrie… …nds. Then, the sample… …for 9 seconds. The sa… …amed MIF300 for 20… …he 20 sec or under… …roperties of over-… …ment. The sample… …are inspected by optica… …state of TLM PR patterning.

Third process … …al deposition. Before metal deposition, removing the native oxide layer is performed to get lower contact resistance and better adhesion betwe… …conductor. The Ni/Ti/Pt/Ti/Pt … …posited by the electron … Each thickness of a m… …ach deposition rate… …ter metal depositi… to eliminate the u… …R) by acetone and … DI water rinsing and…

Fourth process … Mesa structure limits curren… …in Fig. 8, to measure more accurate resistance.[4] PR patterning is performed to protect the metal layer. We used dry etching technique named inductive coupled plasma-reactiv… …ber (ICP-RIE) to make the mesa stru… …plasma based on an advanc… …ntages of ICP-RIE are t… …y controlling an ion … of the etching par… …on of 30 sccm, RF … 200 watt, and cha… … time of the etch… etching sample mater… …ple is needed to remove … …ed for mask and to clean any co…

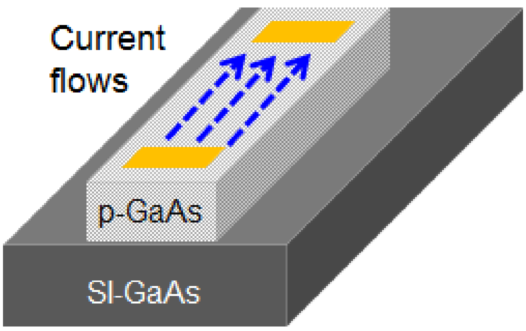

Fig. 8 Mesa structure current flows

Fifth process step is rapid thermal annealing (RTA). The sample is cut to the number of conditions of annealing. The conditions are 340℃ to 460℃ with interval 30℃ for 1 minute.

Final process step is measuring the resistivity values of the properties of the samples by semi-conductor parameter analyzer (4155A). We obtained the results of resistance values with separated lengths of TLM pattern. This sequence of the processes is the common way to make the TLM pattern and measure the resistance for finding the ohmic contact properties.

III. EXPERIMENTAL RESULTS

The experiment is performed by five conditions because we already know that 400℃ is the best condition for low contact resistance[2]. We set 1 minute annealing time for minimizing thermal damages to devices. Table 1 shows the temperature conditions of RTA.

Temp.	340℃	370℃	400℃	430℃	460℃
1 min.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5

Table 1 Experiment conditions

We measured … …h samples and recorded average val… …le 2.

[Unit: Ω]

Wi… / Sample…	…	4 (um)	2 (um)
1		10.14	7.602
2		9.962	7.791
3	…	9.090	7.021
4	…6	9.887	7.229
5	….41	9.347	6.309

Table 2 Tot… …separated lengths

From these da… …aw a graph, illustrate in Fig. 9.

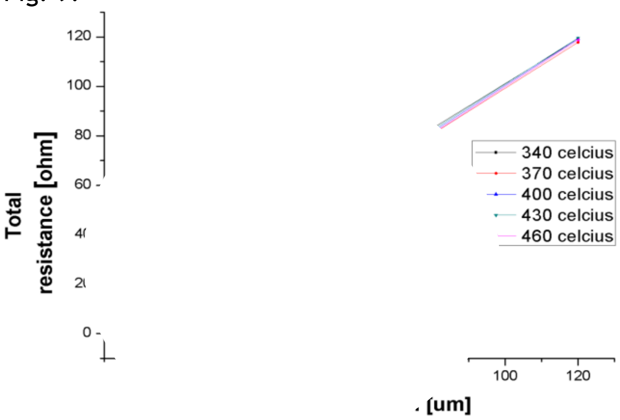

Fig. 9 Total resista… …ues plot

The total resistance differences between each sample are very small, but all the total resistances are increasing by increasing separation width. It means all samples successfully have ohmic contacts.

By using linear-fit plotting, we can know how much these data close to linear plot, illustrated in Fig. 10. The differences between original plots and linear-fit plots are very small. Ohmic contacts have ohmic resistance and one of its properties is to have linearly increasing resistance versus distance of current flow. For better analysis, we calculated the errors between data and linear-fit plots, illustrated in table 3.

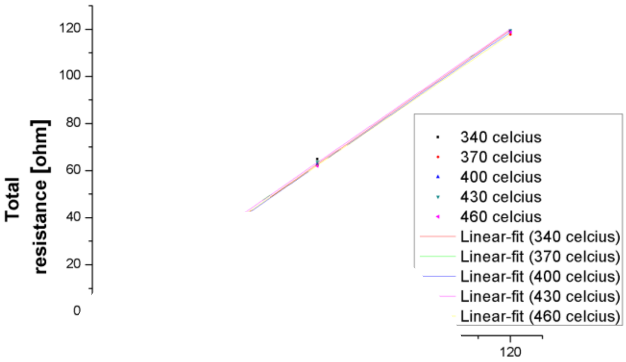

Fig.

Equ			
			ard Error
340 celci			0.00899
370 celcius			0.00523
400 celcius	Slope	0.94862	0.005
430 celcius	Slope	0.9439	0.00973
460 celcius	Slope	0.94408	0.00637

Table 3 Linear-fit plot analysis

The standard error means average errors between linear-fit plot and measured data. All samples have less than 1% error for linear-fit plot. Therefore, measured data linearity is verified.

Next, based on linearity of our data, we got the contact resistance (R_C), sheet resistance (R_{sheet}) and specific contact resistance (ρ_C) that is our main subject, illustrated in Table 4.

Sample	R_C [Ω]	R_{sheet} [Ω/□]	ρ_C[Ω·cm²]
1	3.376	188.9	2.419E-05
2	3.286	185.5	2.335E-05
3	2.859		1.728E-05
4	3.39		8E-05
5	2		-05

Table 4 Calcul

Contact resi The lowest contac 460℃ annealing) an nce comes from sa

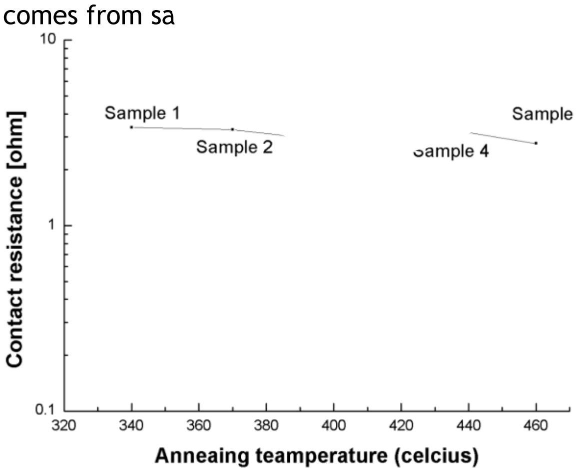

Fig. 11 Contact resistances [Ω]

In log scale graph, there are no big differences between each sample. From this result, we can know that the Ni/Ti/Pt/Ti/Pt metal system has low dependence at temperature section from 340℃ to 460℃ for 1 minute annealing time.

Sheet resistance and specific contact resistance graphs are illustrated in Fig. 11 and Fig. 12.

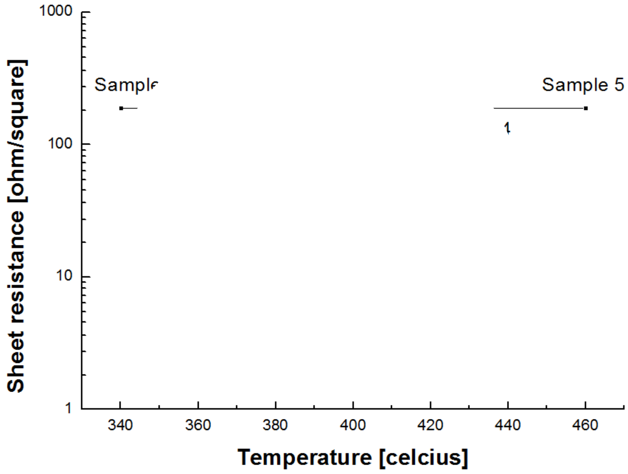

Fig. 12 Sheet resistance (R_{sheet} [Ω/□])

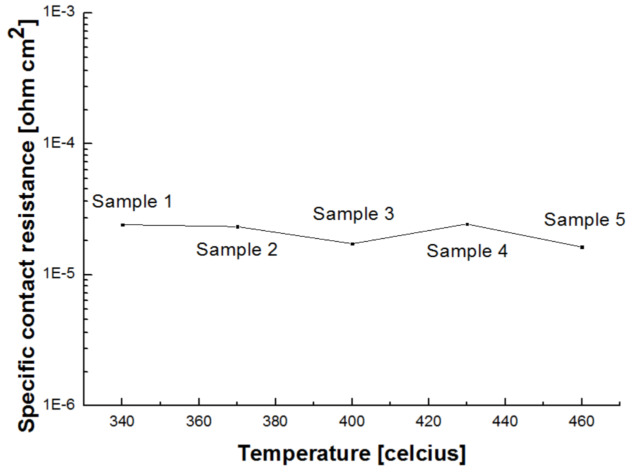

Fig. 13 Specific resistance (ρ_C [Ω·cm²])

The sheet resistance is related with slope of total resistance graph: Slope is R_{sheet}/W and W is 200 um in our case. Co re also very similar each sa cific contact resistanc ach sample, illustrat

IV. DIS

Ni/Ti emperature depende ime. All our results sh eable specific resistance cha sample. However, our specific resistances are neither high nor low. It means our metal system is not suitable for ohmic contact application.

The reason why our metal system has low temperature dependence is that Ni/Ti/Pt/Ti/Pt metal system needs longer annealing time, illustrated in Fig. 14.

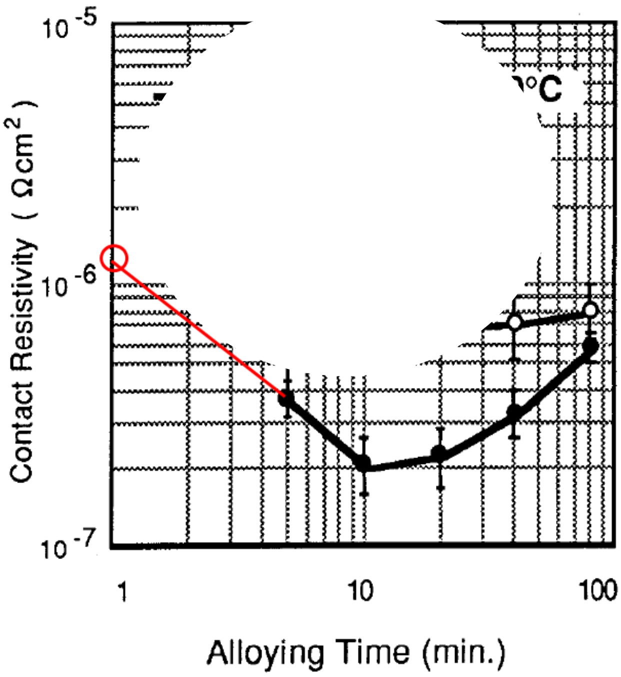

Fig. 14 Time variants of specific contact resistivity[5]

In this metal system, 1 minute annealing time is worst for c- -tact resistance. Here is our assum- -l system needs long ann- - contact resistance. Th- -comes a moderate h- diffusion of Pt to -s the reaction of is too stable for t- : with the GaAs.[2] T- ./Ti layer makes Pt lay- -ect is strong enough to sta- -s and broken slowly by increasing - -e.

This can be a big advantage because temperature reliability is one of the most important requirements of devices. However, the need of long annealing time can cause sev- - to devices.

The p+-GaA- does not have same prop- -eral metal systems, - p-doping and p+-d- -ever, our metal sy- ing GaAs system a- -ent that contains - can be valuable. - metal system's su- by increasing the -

Finally, the re- 2 with very similar p-doping (Be) and - [2] Only one that is - 100 times differe- -e data and our data, - -ent for annealing time the reference's graph.

V. SUMMARY

The Ni/Ti/Pt/Ti/Pt multi-metal layer is used for ohmic contacts to p-type GaAs. The contacts were formed by the sequential e-beam evaporation of 5 nm Ni, 5 nm Ti, 5 nm Pt, 30 nm Ti and 100 nm Pt metal layers onto a 0.3 um Be-doped (2.4 × 10^{19} cm^{-3}) GaAs layer grown by molecular beam epitaxy (MBE). Rapid thermal a- -TA) is performed to get lower conta- -m N_2 gas atmosphere at - - 460°C with interval - -ntact resistance is - -. We obtained the - -nute and tempera-

The lowest - not have special n- - have similar values. V- t/Ti/Pt metal system need- -at causes several damages to dev-

ACKNOWLEDGMENTS

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