

EFFECT OF THERMAL TO OHMIC CONTACT Ge/Au/Ni TO AlGaAs

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ABSTRACT

Ohmic contact of Ge/ Au/ Ni to AlGaAs substrate was studied by varying treatment of the samples with hydrochloric acid and ammonium hydroxide. The samples were etched by wet chemical solutions to determine the most effective solution to remove native oxide that degrades the performance of the devices. The annealing temperature and the length of time were varied to determine the lowest contact resistance. Transmission Line Measurement was used to measure the contact resistance. Result shows that the anneal time at temperature 400 °C for 60 seconds yields the best ohmic contact. The most effective wet solution that can remove native oxide is hydrochloric acids.

INTRODUCTION

GaAs digital IC technology is critically dependent on the availability of the large area wafers that exhibits high resistivity and low crystal defects and etch-pit density [4]. GaAs devices are commonly used for microwave, millimeter waves, optoelectronics and digital application where it has higher electron mobility, is less sensitive to temperature uses, less power and can alloy with additional elements to form materials which various properties compare to silicon.

After 30 years of fabrication of GaAs devices and intergrated circuits, it has established that the best ohmic contacts are made from alloys, and different alloys are needed for n-type and p-type contacts [8]. GaAs processing is very complicated, requiring separate deposition steps, separate masking or etching procedures and so on. An additional problem in extensive use gold-based contacts is very high cost of the base material for GaAs. Poor metallization may not only cause the high contact resistances, high power consumption, slow down the speed of devices but also degrade the performance of devices. It necessary to ensure that the bulk or series resistance of metal semiconductor interface negligibly small during device performance.

Ohmic contacts formation to GaAs using various metal and metal alloy schemes has been studied extensively over the years. This process involves treating the samples with different wet chemical solution and for various materials that deposited onto the GaAs substrate. The existence of native oxide can increase the contact resistance and also degrade of device performance. By elimating the native oxide can form better ohmic

contact. Different compositions of wet chemical have been developed to remove the native oxides successfully.

Annealing condition play important role in behavior of ohmic contact. Annealing process can improve the electronics performance of devices such as carrier lifetime and the mobility electron. A study of specific contact resistance is a function of annealing temperature ranging from 250°C to 400 °C [2]. The effects of various annealing conditions also have been covered.

In this paper, the result of optimization of ohmic contact Ge/Au/Ni to AlGaAs is reported. The variables involve the different cleaning, anneal temperature, and length of anneal time.

EXPERIMENT

The first step of preparation sample is to cleave the 2-inch AlGaAs wafer into small pieces in size from 2 x 2 cm. The sample is cleaved by using diamond saw. The purpose of cleaving the wafer into small pieces is to prepare the sample easily and to save the wafer because the wafer is too limited and expensive

After cleaving, the wafer must be cleaned by using Acetone in 3 minutes. After that, the sample is put into Iso Propyl Alcohol in 3 minutes and rinsed with Deionization water. After rinsed with Deionization water, the wafer is dried by using nitrogen. The purpose of this step is to remove the dust and others forms of airborne and human contamination that can degrade the performance of the device.

The wafers are then force dried and given short bake to remove residual surface moisture, permitting good resist adhesion. Careful control of wafer pre-treatment is essential in maintaining high imaging quality, and this step is critical for this reason. Any defects or contamination allowed at this stage of wafer processing can only magnified by subsequent processing. The final stage of pre-treatment usually involves the application of resist adhesion promoter. This serves as an interfacial layer between the GaAs and the photoresist. Wafers are coated immediately after priming.

Spin coating is the most widely used techniques for applying photoresist of the wafer. The resist is dispended onto the surfaces of the wafers, which are then accelerated on a coater to provide a thin uniform film across every wafer surface. The speed of the coater is about 3000 rpm in 30 seconds.

Coating is performed in a high controlled clean-room environment with solvent exhaust and the operators with clean-room clothing. This is to avoid the wafer contamination.

The overall objective of this step is to provide uniform and defect - free layer of a photosensitive masking material.

The wafers are then baked on the plate in 100 °C within 60 seconds. This step is called soft baking. Soft baking is used to remove the solvents present in the spin-coated film of resist and is usually performed immediately downstream from the coater in a track-type wafer handling systems. Infrared, conduction and microwave heating are used to drive the solvents from the resist coating, rendering in sensitive exposure energy. Solvents left in the resist film from improper soft baking will cause poor imaging quality, usually from attack by the developer. This is one of the most common types of imaging problems. Properly baked wafers are transported to the exposure station.

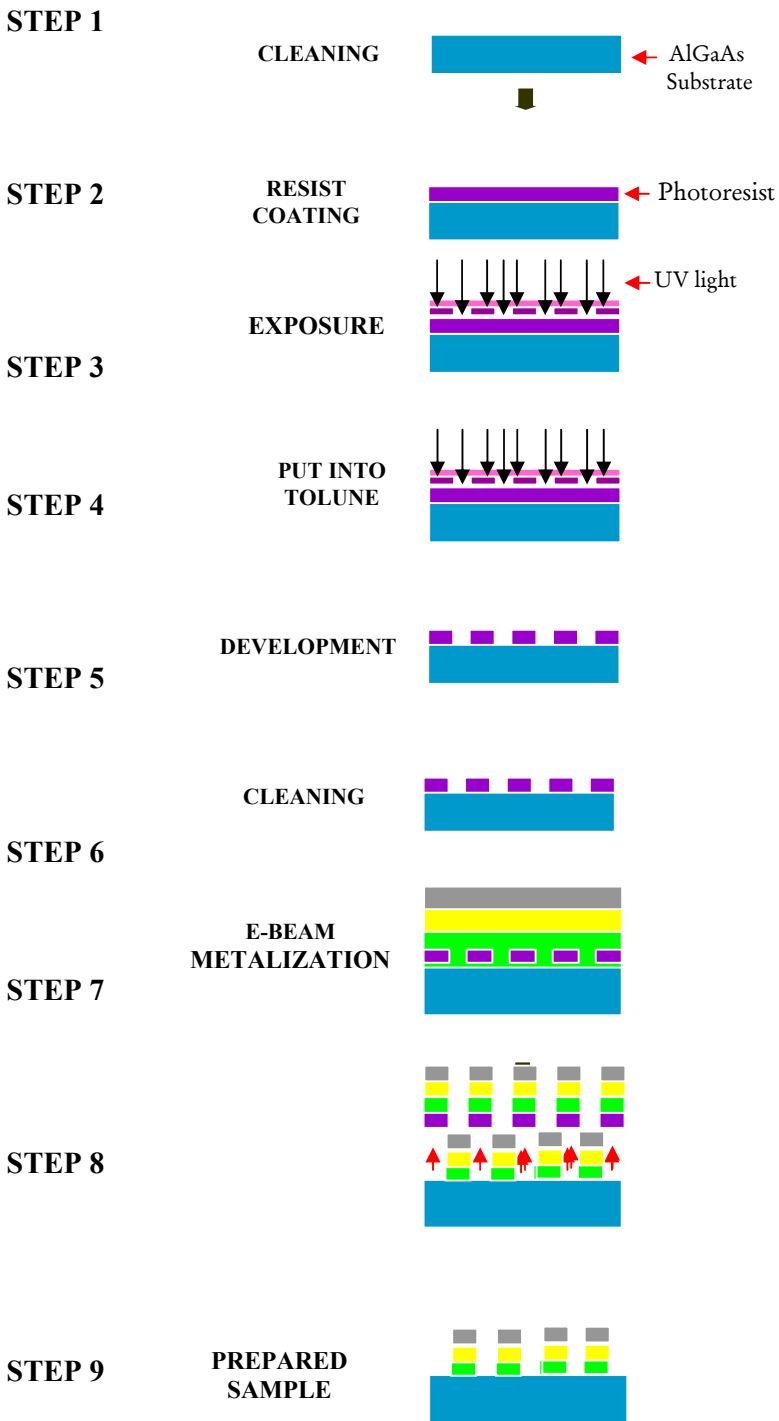


Figure 1: Fabrication Process

The goal of exposure is to transmit the latent image of a desired pattern into the resist film. The role of photo mask is obviously paramount, since the mask is a passive tool that gives the resist its latent image. It must therefore be as clean and defect free as the coated and soft baked wafer hopefully was. The result is a latent image closely matching the pattern of the photo mask. Environmental cleanliness is very important here as well, since contamination on either the wafer or the mask will be reproduced in the final developed image, causing a reject die or wafer, depending on the extent of the contamination. Again properly exposed wafers are transferred to the developer station. Before development process, the wafer is then put into the toluene solution about 30 seconds. The objective of this step is to lift-off the photoresist easily. The wafer is then put into developer. Developer concentration, temperature, and time of development must be closely controlled and monitored to ensure repeatable results. The development time of the wafer is about 60 seconds.

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The development process is one in which the developer selectively attacks and removes either exposed regions (positive resist) or unexposed regions (negative resist), leaving behind the image to serve as the mask for etching or metallization. After developing wafer is rinsed with deionization water and dried.

After developing image on the wafer, the wafers are then cleaned with the chemical solutions. There are two types of the wet chemical solution, which are Hydrochloric acids (HCl), and Ammonium Hydroxide (NH₄OH). Hydrochloric acids (HCl) and Ammonium Hydroxide (NH₄OH) were diluted at 1:20 with Deionization water. The wafers (samples) were treated with wet chemical solution for two minutes. The purpose of this step is to remove the native oxide on the wafer that can degrade the performance of devices.

Metallization is used as the interconnection layer on substrate, making ohmic contact to the devices formed in the AlGaAs. The samples that have been patterned are put into the Electron Beam Evaporation. Deposition of metal by using Electron Beam Evaporation The samples are then deposited with Germanium, Gold, and Nickel, which are deposited layer by layer as shown above. The samples are measured by TLM. After measurement; the wafers or samples are put into Furnace Thermal Anneal equipment (FTA) for annealing process. Annealing condition play important role in behavior of ohmic contact. Annealing process can improve the electronics performance of devices such as carrier lifetime and the mobility electron. Normally, the anneal temperature is between 300-400 °C in a few minutes.

After annealing, the contact resistance of the samples are measured again by using the TLM method. The TLM pattern on the metal is shown in Figure 2.

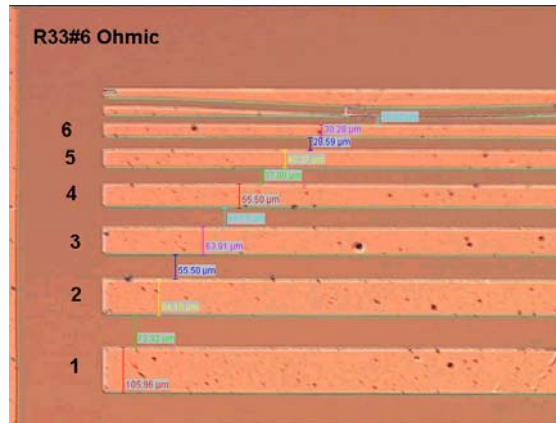


Figure 2: TLM Pattern on the Metal

TRANSMISSION LINE METHOD

The measurement technique that used for measuring the contact resistance is Transmission-Line Model. The theory of the transmission-line model, or transfer length model (TLM), was developed independently by Murrmann and Widmann. [7]. It also was developed by Berger [2].

THEORY

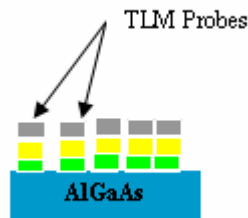


Figure 3: Transmission Line Measurements

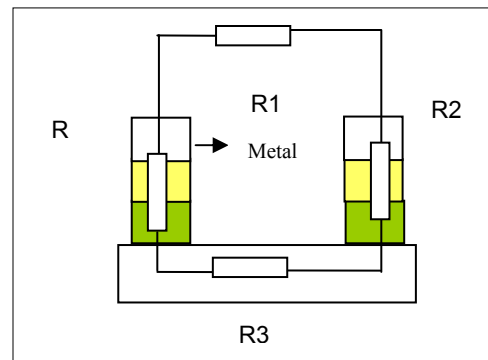


Figure 4: Ohmic Contact Characterizations

A schematic diagram of semiconductor material with ohmic contact pad prepared for TLM Analysis is shown in Figure 5. Between two adjacent pads through two probes, a constant current is passed. The voltage drop is measured by a second set of probes, using a digital volt meter (DVM) enabling the total resistance between the pads to be obtained. Separate current source and DVM are preferred to a single ohm meter because of the latter's relatively low impedance which may give rise to inaccuracies.

From the figure 4 resistors in series can be calculated as below:

$$R_{total}=R_1+R_2+R_3+R_4 \quad (1)$$

$$R_2=R_4=R_c \quad (2)$$

$$R_1=R_p \quad (3)$$

$$R_3=R_s \quad (4)$$

$$R_T=2R_c+R_s+R_p \quad (5)$$

*Ignore resistance due to the probe, R_p

$$R_T=2R_c+R_s \quad (6)$$

Where R_c is the resistance due to the contact, R_s is resistance due to the semiconductor

$$R_s=\frac{\rho l}{d w} \quad (7)$$

But since the sheet resistance, R_{sh} of the semiconductor is given by $\frac{\rho}{d}$, we can write

$$R_T=2R_c+R_{sh}\left(\frac{L}{w}\right) \quad (8)$$

Where R_T is the total of resistance, L is metal increasing pad spacing, w is finite width

$$R_T=2R_c+\left(\frac{\rho}{d}\right)\left(\frac{L}{w}\right) \quad (9)$$

Where R_c is the resistance due to the contact

$$(L_T)^2=\left(\frac{\rho_c}{R_{sk}}\right) \quad (10)$$

Where L_T is the transfer length related to the distance required for current flow into or out of the ohmic contact

$$L_x=\left(\frac{2R_{sk}L_T}{R_{sh}}\right) \quad (11)$$

Where R_{sk} is the modified sheet resistance of the material directly underneath the pads

$$L_T=\left(\frac{R_c w}{R_{sk}}\right) \quad (12)$$

$$\rho_c = L T^2 R_{sk} \quad (13)$$

Where ρ_c is the specific contact resistance

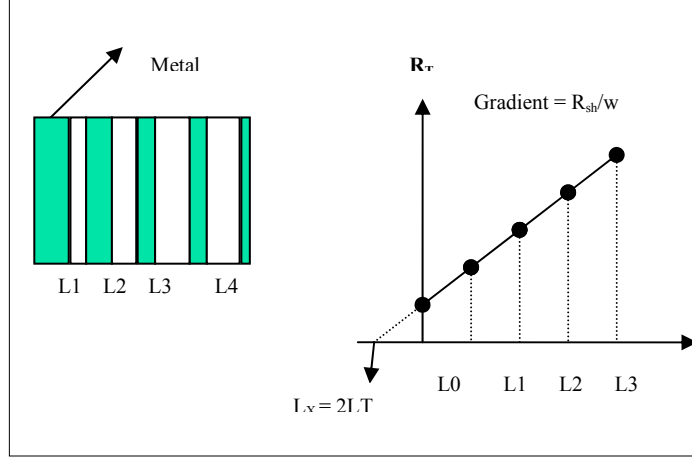


Figure 5: Contact Resistance Measurements

RESULTS AND DISCUSSION

Below table shows the result of all Runcards that have been discussed above.

Table 1: Specific Contact Resistance for Different Cleaning

Cleaning	Specific Contact Resistance, ρ_c ($\Omega\text{-cm}^2$)	
	Before Anneal	Anneal at 400°C for 60 Seconds
HCl	$2.07 \times 10^{+1}$	3.25×10^{-1}
NH ₄ OH	$9.73 \times 10^{+2}$	4.89×10^{-1}

From the Table 1, the lowest specific contact resistance, ρ_c was observed when the sample is treated with HCl for before anneal and after anneal at temperature 400 °C for 60 seconds. Prior the metal contact deposition, the wet chemical etch is usually adopted to remove native oxide for AlGaAs based substrate. The native oxide can degrade the performance of devices. The removal native oxide on the surface of the substrate not only lowers the specific contact resistance but also can improve the uniformity of the contact. The native oxide behaves as a barrier, which inhibits the ohmic metallization reacting with semiconductor.

After annealed at 400°C in 1 minute, we can see that the specific contact resistance decreased. This is because the annealing process can improve the electronics characteristic of the devices.

Table 2: Specific Contact Resistances for Different Anneal Temperature

Temperature (°C)	Specific Contact Resistance, ρ_c (Ω -cm ²)
0	$2.07 \times 10^{+1}$
300	$8.45 \times 10^{+1}$
350	9.55×10^{-1}
400	3.04×10^{-1}

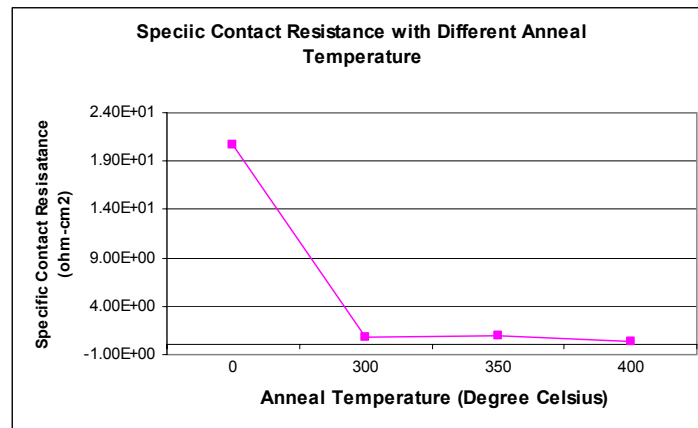


Figure 6: Specific Contact Resistances for Different Anneal Temperature

Table 2 and Figure 1 show the specific contact resistance as a function of anneal temperature. All the samples annealed with temperature range from 300°C to 400°C displaying ohmic behavior. The best ohmic contact occurs at 400°C. Meanwhile, a new regrown GaAs layer doped with high concentrated Ge formed as a result of Ge diffusion provides an electron tunnelling path dominating contact interface. It has been known that severe lattice mismatch may be caused by the large thermal expansion coefficient and high anneal temperature and explains the turnover trend after anneal. Degradation in contact resistance after annealing at 410°C was reported and was correlated with Ge concentration profile diffused into the GaAs [13].

Table 3 Specific Contact Resistances for Different Anneal Time

Anneal Period (s)	Specific Contact Resistance, ρ_c ($\Omega \cdot \text{cm}^2$)
0	$2.07 \times 10^{+1}$
20	$1.18 \times 10^{+1}$
40	$2.07 \times 10^{+1}$
60	$0.874 \times 10^{+1}$

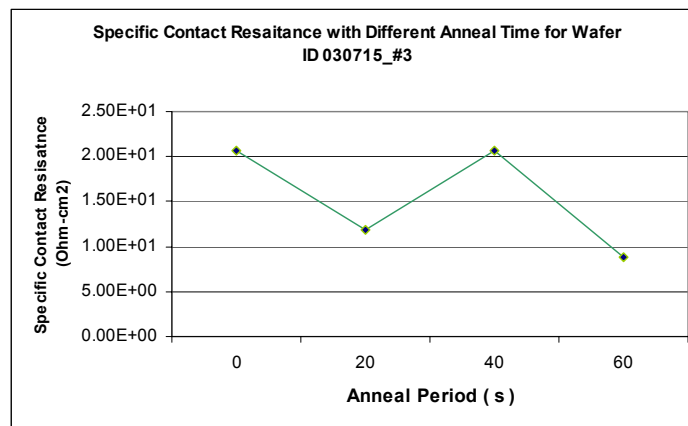


Figure 7: Specific Contact Resistances for Different Anneal Time

To determine the optimal length of anneal time, the samples were annealed for 20 to 60 seconds at 400°C, which achieved the lowest contact resistance, as illustrated in Table 3. It appears that annealing for 60 seconds yields the best ohmic contact as shown in Figure 7. Since the dopant distribution profile is strongly dependent on temperature and anneal time, this explains why anneal time has great effects on specific contact resistance. Actually the annealing process or heat treatment is used to derive the dopant into semiconductor thus creating a tunnelling metal-semiconductor junction required for enhanced ohmic behaviour. Other desirable properties of ohmic contacts include good adhesion to the semiconductor and smooth surface morphology to the semiconductor [6].

CONCLUSION

A study Effect of Thermal to Ohmic Contact Ge/Au/Ni to AlGaAs by varying different cleaning, anneal temperature and period of time for annealing process was conducted. The effect of different cleaning, anneal temperature, period of time for annealing process and the substrate concentration of substrate were investigated. The hydrochloric acid (HCl) treatment can provide sample with surface morphology to minimize the contact resistance. The optimal anneal temperature and length of time of Ge based metal was 400 °C The annealing process at 60 seconds achieved the best ohmic contact.

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