Rapid Thermal Annealing of Ni/Au/Ge Ohmic Contacts to GaAs/AlGaAs Heterostructures with Two Dimensional Electron Gases

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Abstract

With a rapid thermal processor, the annealing of Ni/Au/Ge ohmic contacts to GaAs/AlGaAs heterostructures with 2DEG's can be automated. Finding a suitable recipe for annealing the ohmic contacts that minimizes the contact resistances is investigated. Two classes of heterostructures are considered in this investigation: structures with and without backgate substrates. Samples of each are cleaved and ohmic contacts are made by e-beam lithography and thermal evaporation of Ni, Au, and Ge. For structures without backgates, an annealing step of 425° C for 80 seconds in the rapid thermal processor yielded contact resistances of roughly 4kΩ, which is believed to be the resistance of the 2DEG at room temperature for triangular well samples. For structures with backgates, a trench is etched across the middle of the sample using e-beam lithography and citric acid etch. Ohmic contacts are placed on either side of the trench. On one side, the ohmic contacts are written over the edge of the sample to make contact to the backgate. An annealing step of 400° C for 60 seconds yielded contact resistances of 1kΩ between ohmic contacts on one side of the trench and resistances of the order of 1MΩ across the trench. An annealing step of 425° C for 80 seconds yielded contact resistances of 650Ω between ohmic contacts on one side of the trench and resistances of 400kΩ across the trench. The annealing step of 425° C for 80 seconds seems suitable for both classes of heterostructures; however it may be necessary to have larger resistances across the trench, so the annealing step 400° C for 60 seconds may be preferred for backgated structures.

The fabrication of quantum devices in two dimensional electron gas (2DEG) heterostructures is a lengthy and imprecise process that rarely gives a 100% yield of suitable samples. Thus it is to our advantage to explore new technologies and methodologies that may aid in improving the fabrication process. In particular, this report focuses on improving the step of annealing ohmic contacts.

Electrical contact is made to the 2DEG in a sample by thermally evaporating Ni/Au/Ge onto the sample and heating the sample to a suitable temperature for a certain amount of time to allow the Ni/Au/Ge to melt and diffuse into the GaAs/AlGaAs heterostructure. For the ohmic contacts, the following sequence is evaporated: 50 Å Ni, 50 Å Au, 250 Å Ge, 450 Å Au, 100 Å Ni, 400 Å Au. The Ni layers allow the contact to "stick" to the surface, and the Au layers reduce contact resistance. The Ge layer allows the contact to diffuse into the sample when annealed.

The current method for annealing ohmic contacts requires each sample to be done one at a time. The sample is placed on a wire that is encased in a sealed plastic chamber. The chamber is vented by a valve that lets helium and hydrogen flow through. The current through the wire is controlled by a variable transformer and a thermocouple is attached to the wire to monitor temperature. With the sample placed on the wire and gas flow on, the current is adjusted to bring the sample to the following temperatures for the given amounts of time:

- 110° C for 60 seconds (boils off moisture)
- 250° C for 10 seconds (primes the sample)

- 410° C for 20 seconds or 380° C for 20 seconds for backgated samples (the annealing step)

Afterwards, the transformer is turned off to allow the wire to cool below 40° C and the air flow is turned off. The sample is then rotated 180° and the process is repeated to ensure the sample is evenly annealed.

A major goal in the annealing process is to minimize the contact resistance. This resistance is largely dependent on the temperature and time spent in the last leg of the annealing process. The process described above is effective but is imprecise and can prove to be lengthy for a large number of samples. The temperature along the wire is not constant and the thermocouple reading may not be accurate. The imprecision is not much of a problem for most samples, since they can simply be annealed as often as needed to reach the desired contact resistances. However, for those samples with conductive substrates (backgates), this imprecision can be a problem. With these samples, the goal is to anneal the ohmics to contact the 2DEG without making contact to the conductive substrate several layers below it. Thus these samples are annealed only once to minimize the risk of over-annealing.

These problems can be eliminated by making use of a rapid thermal annealer (RTA). In this system the annealing process can be automated by programming temperature and airflow changes. This automation minimizes human error and imprecision in sample temperature. Thus a suitable recipe for the RTA should yield consistent contact resistances for annealed ohmic contacts. And since the sample holder for the RTA can hold several samples at once, using the RTA can significantly decrease the amount of time spent in the annealing process.

The initial challenge that must be met before making persistent use of the RTA is translating the original annealing recipe to one suitable for the RTA annealing environment. This, however, is not as straightforward as it may appear, since the parameters of the original recipe were derived from experimental trial and error, taking into account the imperfections in the wire and the thermocouple. So like the original recipe, the RTA recipe will have to be determined by experimental trial and error to take into account the different environment of this annealer. Suitable recipes need to be determined for two different classes of sample heterostructures: samples that contain or do not contain a conductive substrate that serves as a backgate.

To find a suitable recipe for annealing sample heterostructures without a backgate, several samples are cleaved from a GaAs/AlGaAs wafer. Polymethylmethacrylate (PMMA) is then applied on the samples as a positive resist, and the ohmic contacts are patterned on the corners of the samples using electron beam lithography. Ni/Au/Ge contacts are then thermally evaporated onto the PMMA resist and the resist is then lifted off by placing the samples in Acetone. After liftoff, each sample resembles the schematic shown in figure 1. These samples are then annealed in the RTA at different anneal temperatures and sitting times. In the experimented recipes, only the last step is changed from the original recipe since this is the step where annealing takes place. After annealing, the contact resistances are measured at room temperature using a 2 probe station.

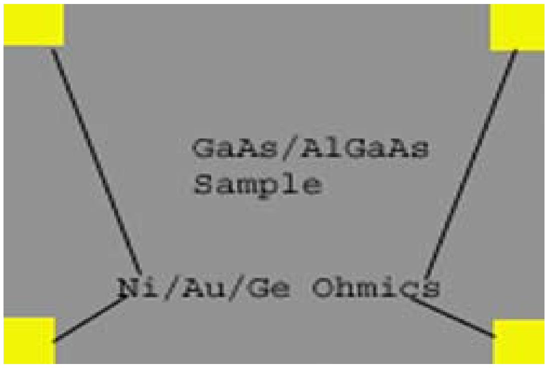

Figure 1: Top-view Schematic of typical non-backgate sample used to determine annealing recipe in RTA

Table 1 summarizes the results obtained from different attempts. The desired contact resistance is near 4kΩ, which is believed to be the resistance of the 2DEG at room temperature for MH samples. In the 4th attempt, such a resistance is achieved with an annealing step of 425° for 80 seconds.

Attempt	**Temperature (° C)**	**Time (s)**	**Average Resistance (Ω)**
1	410°	20	20 kΩ
2	425°	20	20 kΩ
3	425°	40	8 kΩ
4	425°	80	4 kΩ
5	425°	80	5 kΩ

Table 1: Annealing Attempts and Average Contact Resistances obtained with non-backgated samples

To find a suitable recipe for annealing sample heterostructures with a backgate, several samples are cleaved from a GaAs/AlGaAs wafer with a highly doped n-type GaAs substrate. PMMA is then applied on the samples, and a trench running down the middle of the sample is patterned on each sample using e-beam lithography. The trench is then etched by placing the samples in citric acid heated to 50° C. Using a profilometer, the trench depth was measured to be roughly 800 nm deep. Afterwards, ohmic contacts were patterned on each side of the trench for each sample. On one side of the trench, the contacts are patterned over the edges of the samples so that contact can be made to the backgate through cracks on the edges of the samples. On the other side, the contacts are patterned away from the edges to avoid contact to the backgate. Figure 2 shows a schematic of the setup for these samples. With this setup, leakage to the backgate can be examined by measuring contact resistances across the trench.

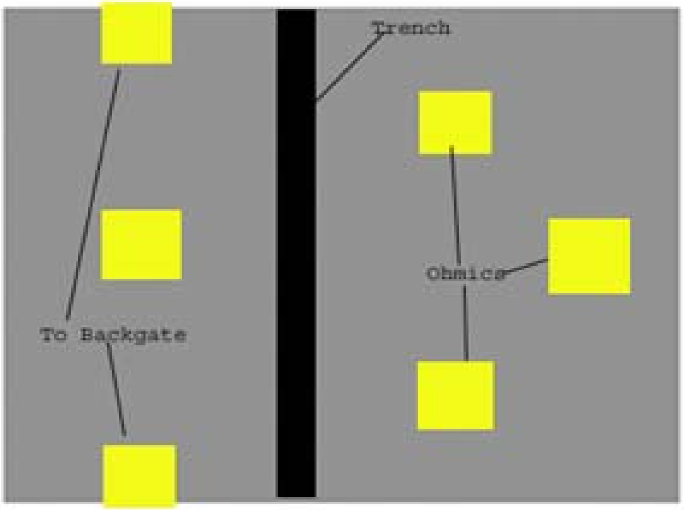

Figure 2: Top-view schematic of typical backgated sample used to determine suitable recipe in RTA. A trench is etched along the middle to electrically isolate the ohmic contacts on either side through the 2DEG. On one side of the trench, ohmics are patterned over the edge of the sample so that any amount of annealing will make a connection to the backgate.

Figure 3 shows plots of contact resistances on one side of and across the trench at 400° annealing temperature for different anneal times. The curves appear to be decaying exponentials with resistances on one side of the trench leveling off to about 1kΩ and resistances across the trench approaching 800 kΩ. The curves were expected to decrease sharply after a certain time, signaling that the contacts were conducting through the low resistance backgate, but this decrease is not seen in the data. This suggests that accidental annealing to the backgate is not as easy as originally thought with the RTA.

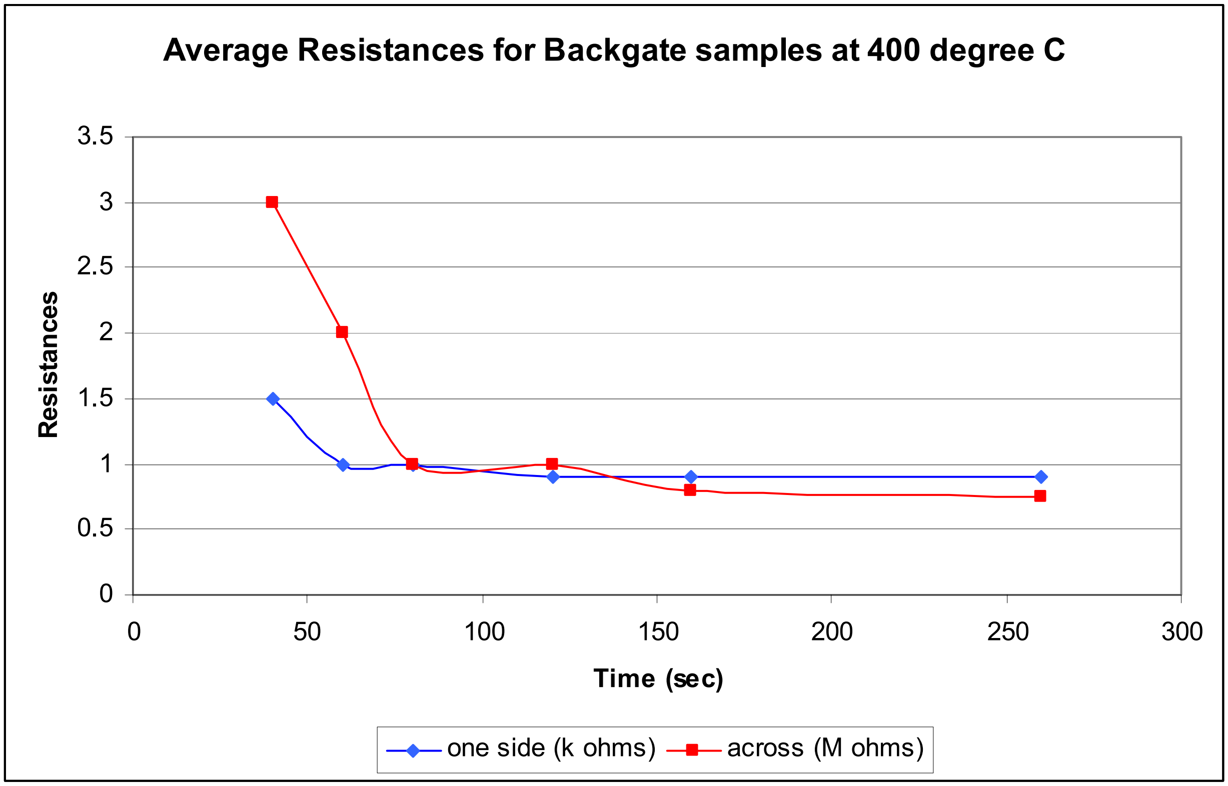

Figure 3: Plots of contact resistances on one side of and across the trench at 400° annealing temperature for different anneal times

Since the contacts did not reach the backgate after long periods of time at 400° C, it appeared to be safe to attempt to anneal one sample at 425° C for 80 seconds. This annealing step resulted in 400 kΩ resistances across the trench and 650 Ω resistances on one side of the trench. These are significantly lower than the results obtained from 400 ° C annealing steps and suggest more leakage to the backgate. However, the resistance across the trench is still large compared to the resistance along one side of the trench. Thus it is believed that this annealing step can be suitable for both samples with and without backgates.

In conclusion, it has been demonstrated that the RTA can be used to yield reasonable contact resistances between ohmic contacts to 2DEG's in GaAs/AlGaAs heterostructures. Specifically for samples with or without backgate substrates, an annealing step of 425° C for 80 seconds yields desirable results in contact resistances. However it may be the case where leakage to the backgate needs to be minimized further. In such a case, an annealing step of 400° C for 60 seconds will be suitable, giving contact resistances near 1kΩ and large trench resistances of the order of MΩ.

References

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