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Plasma Immersion Ion Implantation for Impurity Gettering in Silicon

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Abstract

We have utilized plasma immersion ion implantation (PIII) to demonstrate effective gettering of metallic impurities in silicon wafers. Metallic impurities such as Ni, Cu or Au were intentionally diffused into Si as marker impurities. The Ar or Ne atoms were ionized in an electron cyclotron resonance (ECR) plasma chamber. The ions were accelerated by a negative voltage applied to the wafer and implanted into the wafer. The as-implanted saturation dose can be as high as $5\times10^{16}cm^{-2}$. After an annealing step at 1000°C for 1 hour in a N_2 ambient, the retained doses and the amount of gettered impurities were measured with Rutherford backscattering spectrometry (RBS). With a retained Ar dose in $10^{15}cm^{-2}$ range after annealing, the gettered Ni, Cu and Au were $3.0\times10^{14}cm^{-2}$, $3.0\times10^{14}cm^{-2}$ and $4.4\times10^{13}cm^{-2}$ respectively.

INTRODUCTION

A new ion implantation technique for surface modification, the *plasma immersion ion implantation*, (PIII) has recently been demonstrated [1-2]. In this technique, the substrate is exposed to a plasma containing the ions to be implanted. A high negative voltage applied to the substrate holder accelerates the ions towards the substrate. Using an electron cyclotron resonance (ECR) plasma, PIII systems are capable of providing extremely high dose rate for implantation. Since the ion energy is controlled by the applied voltage, very low energy ion implantation or deposition are possible as well [3-4]. In this paper, we demonstrate that PIII can be used to getter metallic impurities in silicon. It is well-known that implantation of various ions, such as Ar and Ne, can form gettering centers in silicon [5]. This backside gettering technique is costly with conventional ion implanters because of the high dose needed. However, the simplicity and high dose rate capability of PIII makes this gettering step an attractive process.

PIII SYSTEM

The schematic of our experimental PIII system is shown in Figure 1, which consists of an electron cyclotron resonance (ECR) plasma source, an implantation chamber, a high voltage power supply, charge and voltage measurement circuits, and diagnostic apparatus.

A. ECR plasma chamber

The plasma chamber was pumped to a base pressure of about 10^{-7} Torr. Working gas was then fed into the chamber through a gas pressure controller. A constant pressure at 10^{-3} Torr range was maintained during operation. The plasma was excited by 2.45 GHz microwave at the ECR condition. A magnetic field at about 800 Gauss for the resonance was generated by two water cooled coils surrounding the vessel. The output of a microwave generator (not shown in the figure) was controlled by adjusting the magnetron current and guided into the ECR chamber through a quartz window. Two bolometers were used to monitor the forward and reflected microwave power from the generator. A Langmuir probe for measuring ion density, an optical emission spectrometer for detecting excited gas species and a standing wave power meter for checking tuning condition were connected to the system. With a microwave power of 700 watts and an Ar gas pressure of 10^{-3} Torr, the ion density inside the ECR chamber was $1\text{–}5\times10^{12}\text{cm}^{-3}$. In the implantation chamber, an ion density of 10^{11}cm^{-3} was detected.

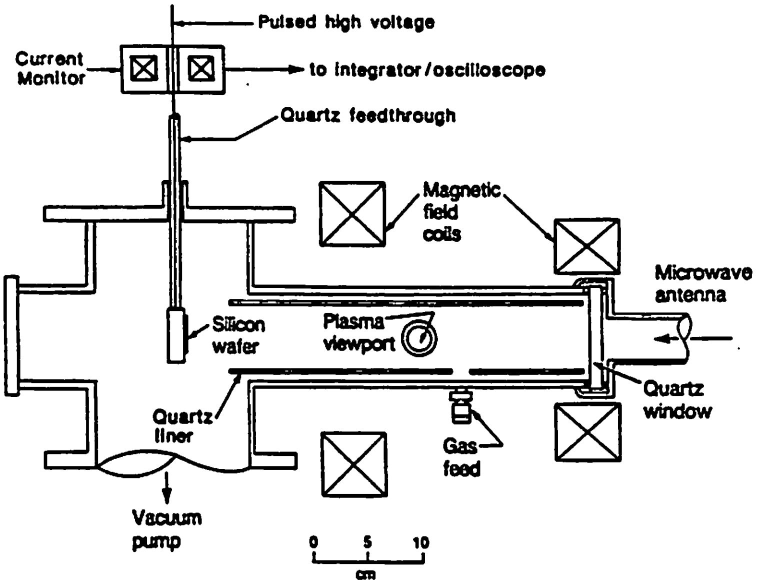
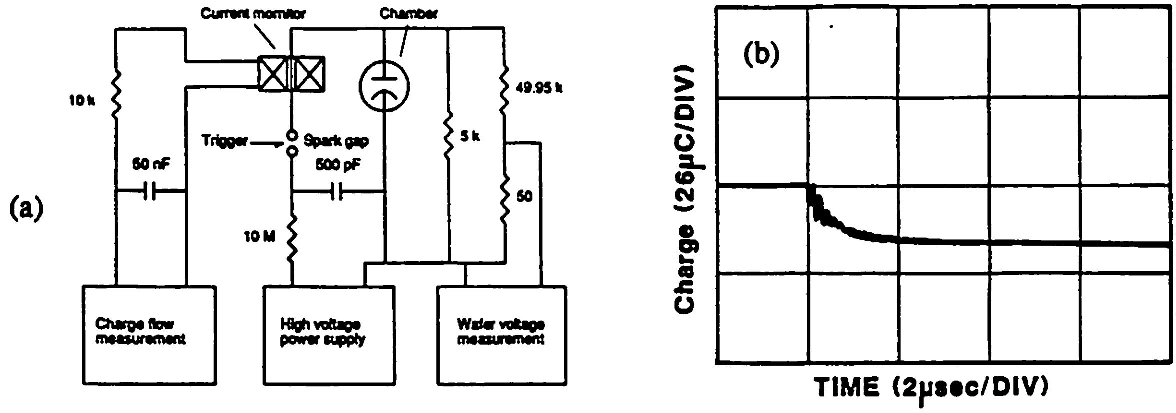


Figure 1. Schematic of the PIII set-up in this study.

B. Pulsed voltage ion implantation

A pulse generator delivers negative voltage pulses to the wafer holder, which accelerates the positive ions towards the wafer. The negative voltage pulses were created by discharging a storage capacitor through a spark gap. The firing of the spark gap was controlled by a triggering signal. The gap was flushed by dry N_2 for stable performance during operation. Since the voltage on the wafer holder decreases as the charge is gradually neutralized by the implanted ions, the ion energy is not mono-energetic. The average potential that the ions experience is about one half of the peak potential. In addition, charge transfer effect in the plasma during acceleration will further reduce the effective implantation energy [6]. A current monitor placed between the high voltage pulse generator and the implantation chamber senses the current flow through the wafer holder. Its output is fed to an integrator to obtain the charge as a function of time. Shown in Figure 2(a) is the equivalent circuit of the charge measurement circuitry. Figure 2(b) is a typical charge output obtained with a storage capacitance of 500 pF charged to -38 kV at an Ar gas pressure of 10^{-3} Torr. The corresponding wafer voltage shown in Figure 2(c) was measured by an oscilloscope through a 1-to-1000 reduction resistor. The duration of each implant pulse is about 1 μsec. The measured total charge per pulse is about 17μC, which is close to the total charge stored in the capacitor (19μC). The accumulated charge divided by wafer holder area and electron charge will give an estimated dose. Due to secondary electron emission and other losses discussed later in this paper, the actual implanted dose can be much less then the estimated dose. Nevertheless, the estimated dose can be treated as an upper-limit dose, which is useful for dose dependence studies. With pulse mode operation, the time-average ion current is proportional to the pulse rate. The maximum pulse rate of our experimental set-up is 30Hz.



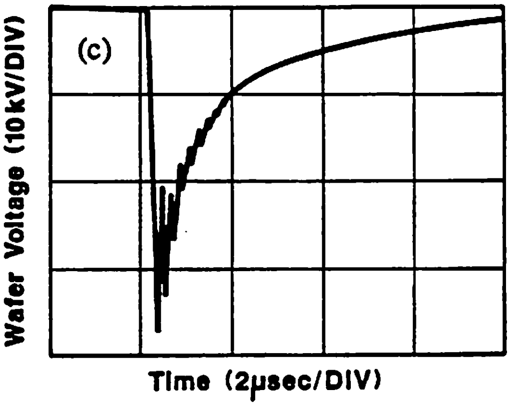


Figure 2. (a) Equivalent circuit for the charge measurement circuitry. It measures the charge that flows through the wafer holder as a function of time. (b) A typical output showing the charge as a function of time during the pulsed implant process. The duration of each implant pulse is about within 1 μsec. (c) The wafer voltage decay during a single pulse process measured by an oscilloscope through a 1-to-1000 reduction resistor.

C. DC voltage ion implantation

Instead of using pulsed voltage, an alternative approach for PIII is to apply a negative DC potential directly to the wafer holder. In this configuration, the charge rate was measured by a current meter. The dose was simply controlled by the implantation time. In this way, extremely high implantation dose can be achieved in a time period of seconds. To prevent excessive wafer heating by high current obtained in DC operation mode, the ion flux has to be reduced by lowering the microwave power to ≈ 70 Watts.

GETTERING RESULTS

For the implant gettering experiments, p-type CZ silicon wafers with (100) orientation and resistivity of 15 ohm-cm were used. Ar or Ne was used for the gettering implant, while Ni, Cu or Au were chosen as the marker impurities. The metallic impurity was first evaporated on the backsides of the wafers and then diffused into the wafers at 1000°C for 1 hour. After surface cleaning, the surface of the wafers were subjected to ion implantation with PIII at a negative voltage of 20-40 kV, gas pressure of about 10^{-3} Torr, and a microwave power of 700 watts. The gettering thermal annealing was performed at 1000°C for 1 hour in a N_2 ambient. The implanted dose and the amount of gettered metallic atoms were measured with Rutherford backscattering spectrometry (RBS).

A. Pulsed PIII gettering

Two RBS spectra of Au doped wafers with and without the Ar implantation are shown in Figures 3(a) and 3(b). The gettering effect of Au at the silicon surface due to PIII is evident. No gettered Au could be measured by RBS without the Ar implant, while a layer of Au atoms with areal density of 4.4×10^{13} cm^{-2} was found after an Ar implant with a retained dose of $1.1\times10^{15} cm^{-2}$ after annealing. The Ar to gettered Au ratio was about 25.

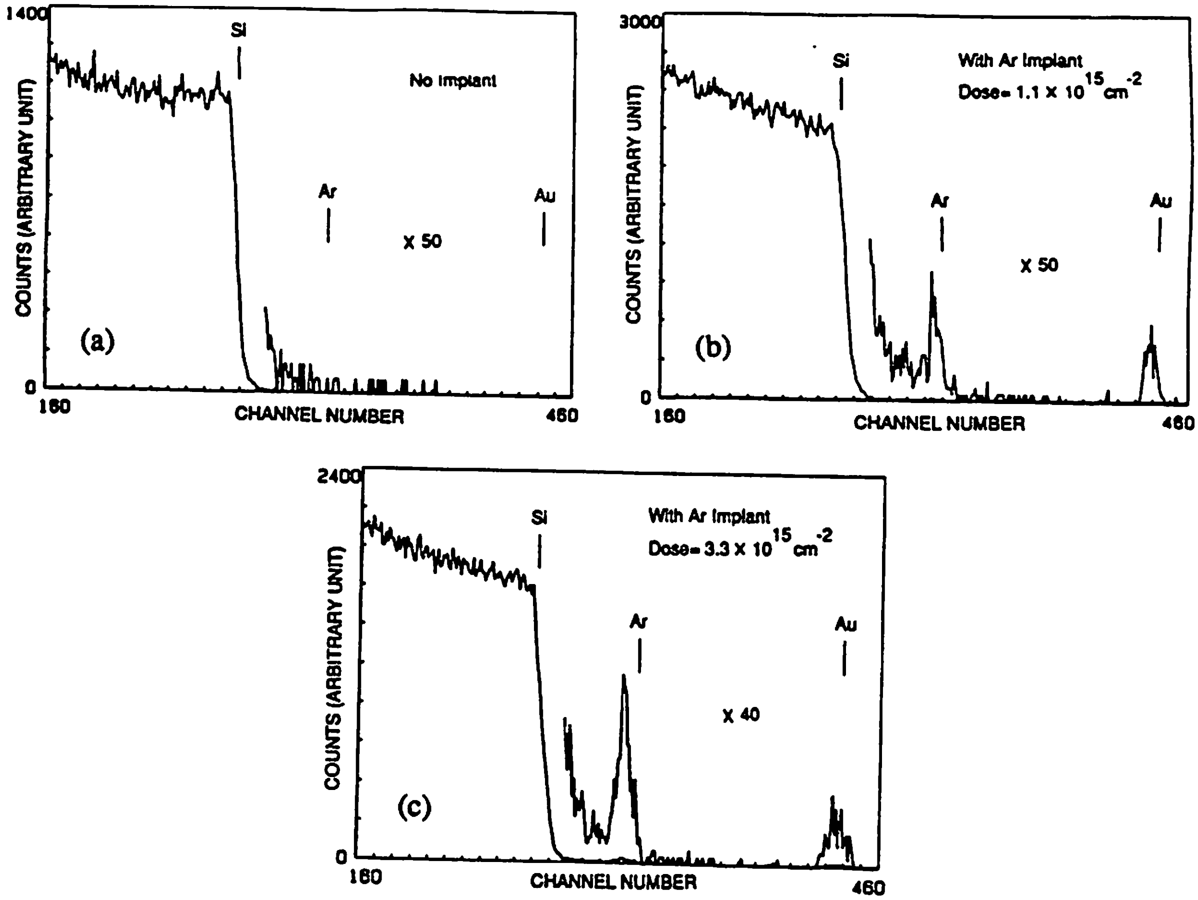


Figure 3. RBS spectra of Au-doped Si wafers. (a) without implant; (b) with Ar implant at a dose of $1.1\times10^{15}cm^{-2}$ and peak voltage of -38 kV. The amount of gettered Au is $4.4\times10^{13}cm^{-2}$. The positions of surface peaks for Ar and Au are marked in the figure. The portion of the spectra containing Ar and Au peaks are magnified 50 times. (c) with Ar implant in DC configuration at a dose of $3.3\times10^{15}cm^{-2}$. The applied DC voltage was -40 kV. The amount of gettered Au is $6.2\times10^{13}cm^{-2}$. The positions of surface peaks for Ar and Au are marked in the figure. The portion of the spectra containing Ar and Au peaks are magnified 40 times.

In Table 1, we summarize the amount of gettered impurities by PIII of Ar and Ne. No marker metallic impurities were detected by RBS in the non-implanted samples. More efficient gettering was found for Ni and Cu impurities, probably due to the larger diffusivities of these metals in silicon. The Ne doses cannot be measured by RBS due to its light mass. However, the gettering of Au is still obvious by comparing samples with and without implantation. From the RBS spectra, the Ar profile was found to peak at about 200 Å below the silicon surface. It should be mentioned that some control silicon wafers without metallic diffusion were also implanted with Ar PIII and analyzed with RBS. No measurable marker impurities were detected in these control wafers after identical annealing conditions.

B. DC PIII Gettering

Impurity gettering was also achieved with PIII in the DC operation mode. Figure 3(c) shows the RBS spectrum of an Ar implanted sample with the wafer holder kept at -40 kV DC during implantation. After annealing at 1000°C for 1 hour, the retained Ar dose was $3.3\times10^{15}cm^{-2}$ and the areal density of gettered Au was $6.2\times10^{13}cm^{-2}$.

TABLE I. Amount of gettered impurities with PIII of Ar and Ne. All samples were annealed at 1000°C for 1 hour in N_2 ambient after PIII.

Retained implant dose (cm^{-2})	Amount of gettered impurity (cm^{-2})
Ar 1.1×10^{15} (pulse)	Au 4.4×10^{13}
Ar 1.2×10^{15} (pulse)	Ni 3.0×10^{14}
Ar 2.4×10^{15} (pulse)	Cu 3.0×10^{14}
Ne 4.7×10^{16} * (pulse)	Au 4.5×10^{13}
Ar 3.3×10^{15} (DC)	Au 6.2×10^{13}
No implant	Gettering not detected by RBS

*Estimated from the total number of discharge pulses and the amount of charge per pulse. The retained dose is much less as discussed in text.

DISCUSSIONS

It was found that the as-implanted Ar is only a fraction of the measured charge that flows through the wafer holder. For example, with measured charge of 8×10^{15} unit charge per cm^2 for pulsed mode operation at -20kV, the as-implanted Ar dose is only $1.2\times10^{15}cm^{-2}$. Similar results have been reported by Tendys, *et al* [2]. This discrepancy can be due to that secondary electron emission from the negatively biased substrate and the implanted Ar ions may have multiple ionization states. In addition, surface sputtering and Ar out-diffusion will remove part of the implanted Ar from the substrate. We also found that the as-implanted Ar dose shows saturation as the amount of total charge increases. By increasing the wafer holder voltage from -20 kV to -38 kV, an increase of Ar saturation dose was observed. Evidently the deeper implantation of higher energy ions suppressed the out-diffusion effect and reduced the percentage of shallow implants which was removed by sputtering.

We noticed that for most gettering samples the retained doses after thermal annealing at 1000°C for 1 hour is in the low 10^{15} range in spite of very different as-implanted doses. More than 50 percent of the Ar can be retained for samples with 10^{15} as-implanted doses. However, the percentage of retained dose is getting lower when the dose gets higher. A pair of RBS spectra before and after annealing is shown in Figure 4. The as-implanted Ar dose of this sample was $4.5\times10^{16}cm^{-2}$. After annealing, the retained dose was only $3.3\times10^{15}cm^{-2}$. By comparing the positions of the Ar peaks, it is clear that the retained Ar profile is in the deeper wing of the as-implanted profile. This suggests the substantial Ar loss is an out-diffusion mechanism during the gettering annealing step. It's interesting to note that the gettered Au profile coincides with as-implanted Ar profile, both peak at the depth of 280Å. This observation suggests that the metallic impurities were trapped by implantation defects instead of the implant species.

With our present experimental set-up, 10^3 pulses will be needed for a dose of $10^{15}cm^{-2}$ over a $50cm^2$ wafer holder area. It will takes several minutes for a 30 Hz pulse generator. Since the pulse duration is only about 1 µsec, the pulse rate can be raised by many orders for high dose rate requirements. In the case of DC, our preliminary data shows that an Ar dose of $4.2\times10^{16}cm^{-2}$ was obtained in 10 seconds. This dose rate is extremely high comparing with conventional ion implanters.

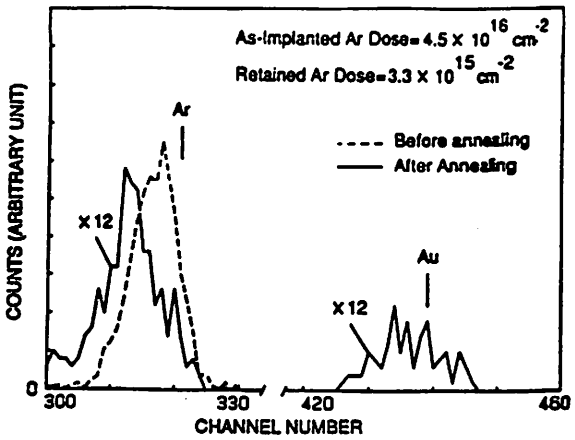


Figure 4. RBS spectra of an Au-doped Si wafer before and after annealing. The Ar was implanted in DC mode at -40 kV for 1 minute. The thermal annealing was performed at 1000°C for 1 hour in N_2 ambient. The after-annealing Ar and Au yields are magnified 12 times.

CONCLUSIONS

We have demonstrated plasma immersion ion implantation of Ar and Ne in both pulsed and DC modes with an ECR plasma source. The as-implanted saturation dose can be as high as $5\times10^{16}cm^{-2}$. This novel implantation technique was successfully applied to getter Au, Ni and Cu in silicon. Considerations for charge collection, surface sputtering, out-diffusion, and the effect of extremely high dose rate implantation are also discussed.

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PLASMA IMMERSION ION IMPLANTATION AND DOSE LOSS IN IMPURITY GETTERING EXPERIMENT

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ABSTRACT

We have demonstrated gettering of metallic impurities in silicon wafers with plasma immersion ion implantation (PIII). Ar or Ne gas was ionized in an electron cyclotron resonance (ECR) plasma chamber. The positive charged ions were accelerated by a negative voltage applied to the wafer and implanted into the wafer. Metallic impurities were intentionally introduced into Si through thermal diffusion as marker impurities before implantation. The as-implanted dose was around $1\times10^{16}cm^{-2}$. After an annealing step at 1000°C for 1 hour in a N_2 ambient, the retained doses and the amount of gettered impurities were measured with Rutherford backscattering spectrometry (RBS). With a retained Ar dose in the $10^{15}cm^{-2}$ range after annealing, the gettered Ni, Cu and Au were $3.0\times10^{14}cm^{-2}$, $3.0\times10^{14}cm^{-2}$ and $4.4\times10^{13}cm^{-2}$ respectively. A discrepancy between implanted Ar dose and estimated Ar dose from charge integration was found and a model is proposed to explain this discrepancy. The Ar loss mechanism during gettering annealing has also been investigated.

INTRODUCTION

Ion implantation is a crucial technology in modern integrated circuit fabrication. During this process, extremely precise amounts of elements such as boron, phosphorus, or arsenic are injected into the silicon substrates to modulate their electrical properties. Conventional ion implantation is carried out in a vacuum environment, in which an ion source is used to create an intense beam of ions of the species to be implanted. After mass selection, the ion beam is accelerated towards the substrate.

Then the beam is run until the desired dose is accumulated in the target. There is a continuous quest in the implantation industry to improve ion source performance, because the available ion current limits implantation throughput. Due to the complexity of conventional implanter ion optics, it is difficult to produce a very low energy ion beam, which is needed for very shallow ion implantation in the fabrication of ultra-compact integrated circuits.

Recently Conrad [1] and Tendys [2] have demonstrated a new ion implantation technique, the *plasma immersion ion implantation* (PIII). They successfully applied this technique to improve the wear and corrosion resistance of materials. In PIII the intermediate step of the ion source and all its support equipment are completely omitted. The substrate is exposed to a plasma containing the ions to be implanted. A high negative voltage applied to the substrate holder accelerates the ions towards the substrate. Using an electron cyclotron resonance (ECR) plasma, PIII systems are capable of providing extremely high dose rate for implantation. Since the ion energy is controlled by the applied voltage, very low energy ion implantation or deposition are possible [3-4]. Instead of the high vacuum condition required for conventional implantation, PIII works over a pressure range from 0.1 to 100 Torr. An adjustable ion angular distribution can be realized by controlling the gas pressure. This feature is very attractive for conformal implantations of nonplanar surface topographics in advanced integrated circuit structures.

PIII can also operate in a triode mode by introducing a sputtering target between the ECR source and substrate. With a suitable bias to the target, the sputtering rate can be controlled. The sputtered atoms from solid target can be ionized, accelerated and implanted to the substrate together with working gas ions. This triode system can be very useful for dual ion implantations and ion-beam assisted deposition. The feature of triode configuration is the capacity to implant any solid material into the substrate, as long as that solid has reasonable sputtering and ionization rate. This feature is useful for implanting materials such as noble metals, where nonvolatile gaseous precursors do not exist.

In this paper, we report the application of PIII in gettering metallic impurities in silicon. It is well-known that implantation of various ions, such as Ar and Ne, can form gettering centers in silicon [5]. This backside gettering technique is costly with conventional ion implanters because of the high dose needed. However, the simplicity and high dose rate capability of PIII makes this gettering step an attractive process.

PIII APPARATUS

Our experimental PIII system shown in Figure 1 consists of an electron cyclotron resonance (ECR) plasma source, an implantation chamber, a high voltage power supply, charge and voltage measurement circuits, and diagnostic apparatus.

The chamber was pumped with a diffusion pump through a liquid nitrogen cold trap to a base pressure of 10^{-7} Torr. Working gas such as Ar or Ne was then fed into the chamber. A constant gas pressure at 10^{-3} Torr range was maintained during operation using a gas pressure controller. The plasma was excited by 2.45 GHz microwaves at the ECR condition. An axial magnetic field was generated by two water cooled coils surrounding the vessel. To achieve the ECR resonance condition, a magnetic field of 875 Gauss is needed. The output of the microwave generator (not shown in the figure) was guided into the ECR chamber through a quartz window. Two bolometers were used to monitor the forward and reflected microwave power. The output microwave power was controlled by adjusting the magnetron current. A Langmuir probe for measuring ion density, an optical emission spectrometer for detecting excited gas species and a standing wave power meter for checking tuning condition were connected to the system. With a microwave power of 700 W, a magnet current of 150 A, and an Ar gas pressure of 10^{-3} Torr, the ion density near the wafer holder was around 10^{11}cm^{-3}. Inside the ECR chamber, a higher density of $1-5\times10^{12}\text{cm}^{-3}$ was detected.

The wafer holder was biased by a negative voltage to accelerate the implant ions. In case a large dose rate is needed, a DC negative voltage was applied. In this configuration, the charge rate was measured by a current meter. The dose was simply controlled by the implantation time. In this way, extremely high implantation dose can be achieved in a time period of seconds. To prevent excessive wafer heating by high current, the ion flux has to be reduced by lowering the microwave power to ≈ 70 Watts.

When a better dose control is needed, pulsed voltage can be used. In this mode, a high voltage pulse generator delivers negative voltage pulses to the wafer holder, which accelerates the positive ions towards the wafer. The negative voltage pulses were created by discharging a storage capacitor through a spark gap. The firing of spark gap was controlled by a triggering signal. A current monitor placed between the high voltage pulse generator and the implantation chamber sensed the current flow through the wafer holder. Its output was fed to an integrator to obtain the charge as a function of time. The accumulated charge divided by wafer holder area and electron charge gave an estimated dose. Due to secondary electron emission and other losses discussed later in this paper, the actual implanted dose can be much less then the estimated dose. However, the estimated dose can be treated as an upper-limit dose, which is useful for dose dependence studies. With pulse mode operation, the time-average ion current was proportional to the pulse rate. The maximum pulse rate of our experimental set-up was 30Hz.

IMPURITY GETTERING EXPERIMENTS

In these experiments, p-type CZ silicon wafers with (100) orientation and resistivity of 15 ohm-cm were used. Ni, Cu or Au were chosen as marker impurities. The metallic impurity was first evaporated on the backsides of wafers and then diffused into the wafers at 1000°C for 1 hour. After surface cleaning, the surface of the wafers were subjected to ion implantation with Ar or Ne PIII at a negative DC or pulsed voltage of 20-40 kV. During operation, the gas pressure was about 10^{-3} Torr, and the microwave power was 700 watts. The gettering thermal annealing was performed at 1000°C for 1 hour in a N_2 ambient. The as-implanted dose, retained dose after thermal annealing, and the amount of gettered metallic atoms were measured with Rutherford backscattering spectrometry (RBS). Control wafers without PIII were also measured by RBS for comparative studies.

Two RBS spectra of Au doped wafers with and without the Ar implantation are shown in Figures 2(a) and 2(b). The gettering effect of Au at the silicon surface due to PIII is evident. No gettered Au could be measured by RBS without the Ar implant, while a layer of Au atoms with areal density of 4.4×10^{13} cm^{-2} was found after an Ar implant with a retained dose of 1.1×10^{15}cm^{-2} after annealing. No marker metallic impurities were detected by RBS in the non-implanted samples.

Figure 2(c) shows Ne implant gettering. The implanted Ne atoms cannot be measured by RBS due to their light mass. However, the gettering of Au is observed by comparing samples with and without implantation. An areal density of 4.5×10^{13}cm^{-2} of Au was detected in the surface of Ne implanted wafer, while no Au was measured in the wafer without Ne implantation.

More efficient gettering was found for Ni and Cu impurities, probably due to the larger diffusivities of these metals in silicon. An areal density of 3×10^{14}cm^{-2} of Ni was gettered for a retained Ar dose of 1.2×10^{15}cm^{-2}, as shown in Figure 3(a) and 3(b). The same amount of Cu was gettered in a Cu diffused wafer with an Ar dose of 2.4×10^{15}cm^{-2}. In all cases, no measurable marker impurities were detected by RBS in control wafers after identical annealing processing.

It is worth to mentioning that impurity gettering implantation can be performed in both pulsed and DC modes. As a comparison with pulsed implantation for the experiments above, the gettered Au was 6.2×10^{13}cm^{-2} for a retained Ar dose of 3.3×10^{15}cm^{-2} implanted in DC mode.

We noticed that for most gettering samples the retained doses after thermal annealing at 1000°C for 1 hour are in the low 10^{15}cm^{-2} range inspite of very different as-implanted doses. More than 50 percent of the Ar can be retained for samples with as-implanted dose in the range of 10^{15}cm^{-2}. However, the percentage of retained dose decreases for higher dose. A pair of RBS spectra before and after annealing are shown in Figure 4. The as-implanted Ar dose of this sample was 4.5×10^{16}cm^{-2}. After annealing, the retained dose was only 3.3×10^{15}cm^{-2}. By comparing the positions of the Ar peaks before and after annealing, it is clear that the retained Ar profile is in the deeper wing of the as-implanted profile. This suggests the substantial Ar loss is an out-diffusion mechanism during thermal annealing. It is interesting to note that the gettered Au profile coincides with as-implanted Ar profile, both peak at a depth of 280Å. This observation suggests that the metallic impurities were trapped by implantation induced damage instead of the implant Ar.

SECONDARY ELECTRON EMISSION AND SPUTTERING IN PIII

For low energy implantation in the keV energy range, surface sputtering can be important. Secondary electron emission from wafer surface is also expected because of the high negative voltage applied to the wafer holder. For a good control of the PIII process, it is important to evaluate the effect of these phenomena. Figure 5 shows the implanted Ar dose as a function of total discharge per wafer holder area. First, we observe that the implanted Ar is only a fraction of the measured charge collected by the wafer holder. At a total charge of 1.2×10^{16} electron charge per cm^2, the measured Ar dose is only $1.6\times10^{15}cm^{-2}$. Similar results have been reported by Tendys, *et al* [2]. Secondly, we notice that the implanted Ar dose shows saturation as the amount of total collected charge increases.

These phenomena can be understood with the following model. Since secondary electrons are emitted from the negatively biased substrate during implantation, only a fraction of the measured current that flows into wafer holder is due to the ion flux. The implanted Ar ions may have multiple ionization states, so that the implanted Ar dose will be less than expected if they were all single ionized. In addition, surface sputtering and Ar out-diffusion will remove part of the implanted Ar from the substrate. Let J be the measured current density divided with electron charge and Φ be the ion dose in the substrate. We can express the ion flux as βJ with $0 < \beta < 1$. The term $(1 - \beta)$ represents the secondary electron emission and the multiple ionization losses. As a first order approximation, the Ar loss rate due to sputtering and out-diffusion can be modeled with a term $-\alpha\beta J\Phi$, where α is a proportional factor. The time rate of Φ is then,

$$\frac{d\Phi}{dt} = \beta J - \alpha\beta J\Phi. \tag{1}$$

The solution of this equation is

$$\begin{aligned}\Phi &= \frac{1}{\alpha}(1-e^{-\alpha\beta Jt}) \\ &= \frac{1}{\alpha}(1-e^{-\alpha\beta Q})\end{aligned} \tag{2}$$

where Q is the total discharge in electron charge per unit area that flows through the wafer holder. Equation (2) indicates the implanted dose will saturate at $\frac{1}{\alpha}$. As shown in Figure 5, this functional dependence fits the experimental data quite well, with the extracted values of α and β being $0.35\times10^{-15}cm^2$ and 0.28 respectively for a wafer voltage at -20 kV. These results indicate that the saturation dose is around $3.0\times10^{15}cm^{-2}$ and about 28% of the current discharged through the wafer holder contributes to the ion flux. By increasing the wafer voltage from -20 kV to -27 kV, an increase of Ar saturation dose is observed (dashed line in Figure 5). Evidently the deeper implantation of higher energy ions suppressed the Ar out-diffusion effect and reduced the percentage of shallow implants which was removed by sputtering.

CONCLUSIONS

We described an experimental PIII apparatus and discussed the versatile applications of PIII for VLSI fabrications. Metallic impurity gettering was demonstrated with an ECR Ar or Ne plasma source. This implantation technique was successfully applied to getter Au, Ni and Cu in silicon. An Ar out-diffusion process during thermal annealing was found and the implantation induced damage gettering mechanism was discussed. A model to account for secondary electron emission, multiple ion charge states and substrate surface sputtering is proposed.

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FIGURES

Figure 1.

Schematic of the PIII system. The chamber was pumped to a base pressure of 10^{-7} Torr. The output of a 2.45 GHz, 800 W microwave generator (not shown in the figure) was guided into the ECR chamber through a quartz window. The wafer holder was biased by a high negative voltage to accelerate the implant ions.

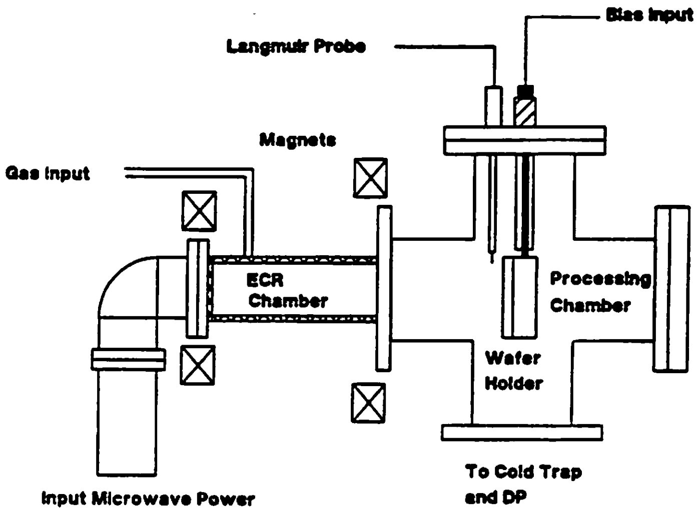
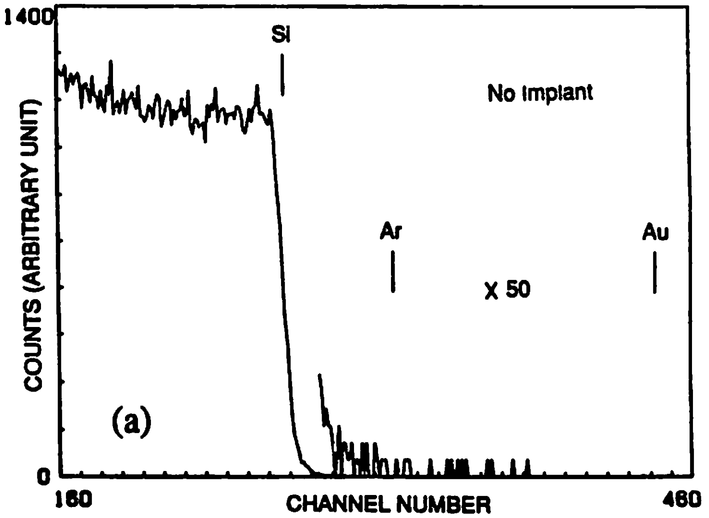
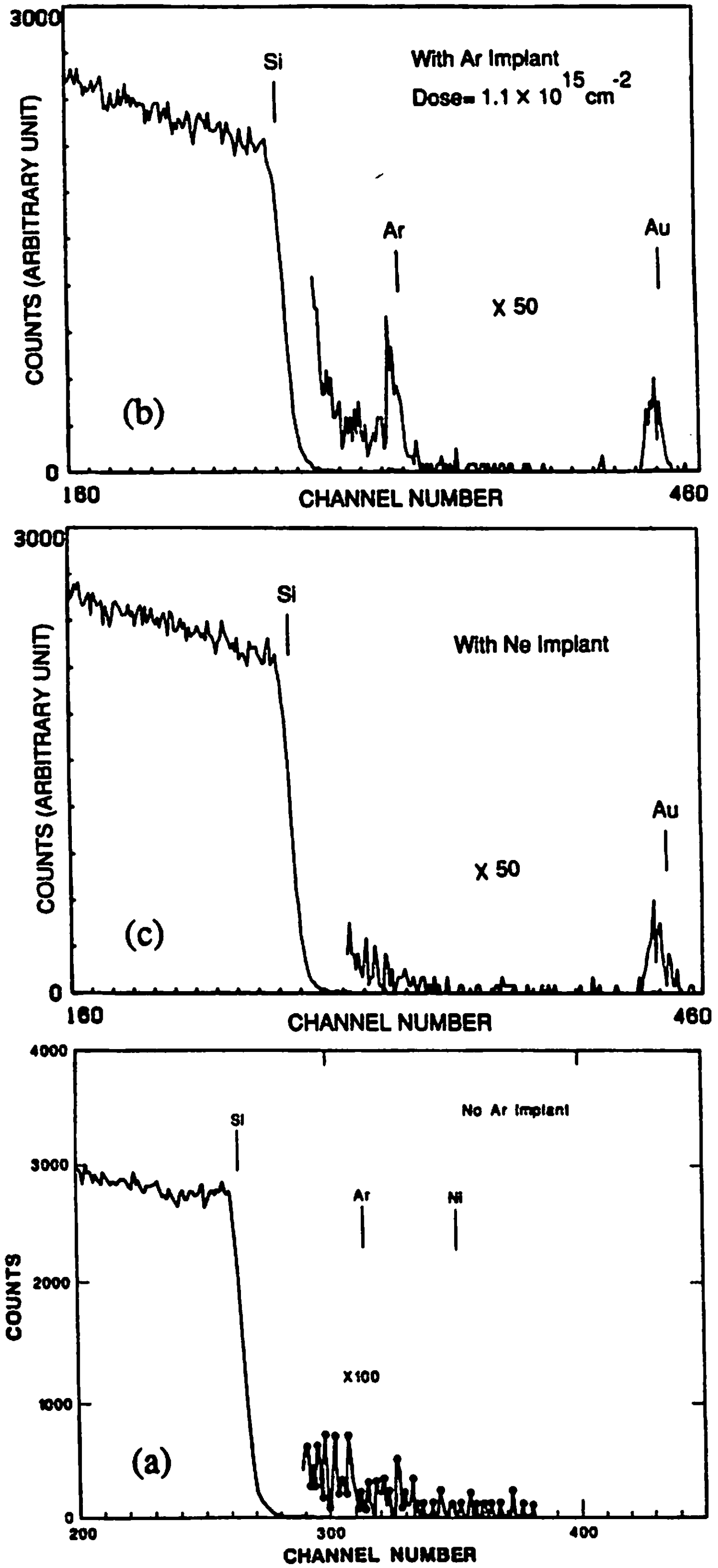


Figure 2.

RBS spectra of Au-doped Si wafers.

(a) without implant;





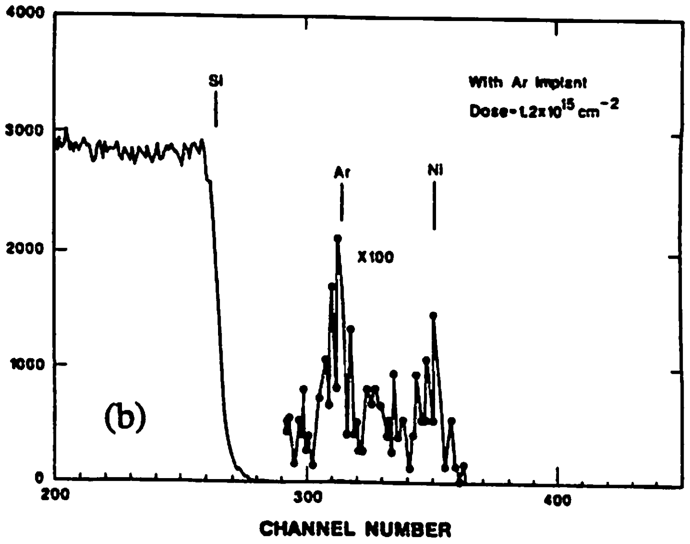
(b) with Ar implant at a dose of 1.1×10^{15}cm^{-2} and peak voltage of -38 kV. The amount of gettered Au was 4.4×10^{13}cm^{-2}. The surface peak positions of Ar and Au were marked in the figure. The portion of the spectra containing Ar and Au peaks was magnified 50 times;

(c) with Ne implant. The bias pulse peak voltage was -38 kV. The amount of gettered Au was 4.5×10^{13}cm^{-2}. The Au surface peak position was marked in the figure. The portion of the spectrum containing Au peak was magnified 50 times. The wafers were annealed at 1000°C for 1 hour.

Figure 3.

RBS spectra of Ni-doped Si wafers.

(a) without implant;



(b) with Ar implant at a dose of 1.2×10^{15}cm^{-2} and peak voltage of -20 kV. The amount of gettered Ni was 3×10^{14}cm^{-2}. The surface peak positions of Ar and Ni were marked in the figure. The wafers were annealed at 1000°C for 1 hour.

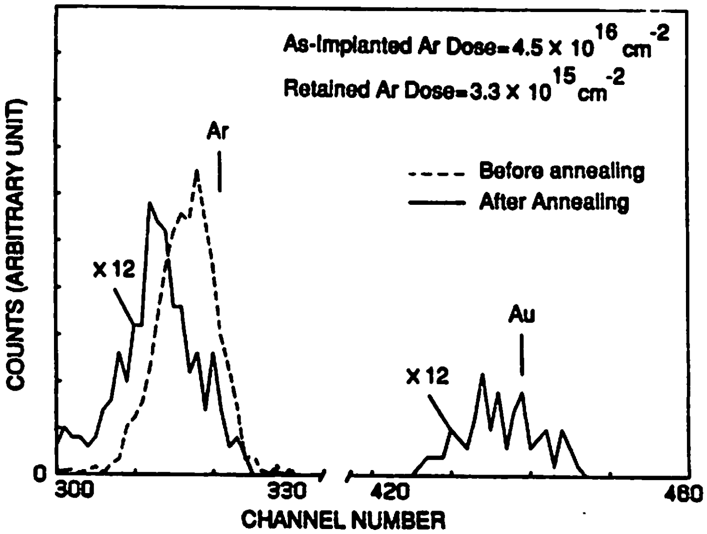


Figure 4.

RBS spectra of an Au-doped Si wafer before and after annealing. The Ar was implanted in DC mode at -40 kV for 1 minute. The thermal annealing was performed at 1000°C for 1 hour in N_2 ambient. The after-annealing Ar and Au yields were magnified 12 times.

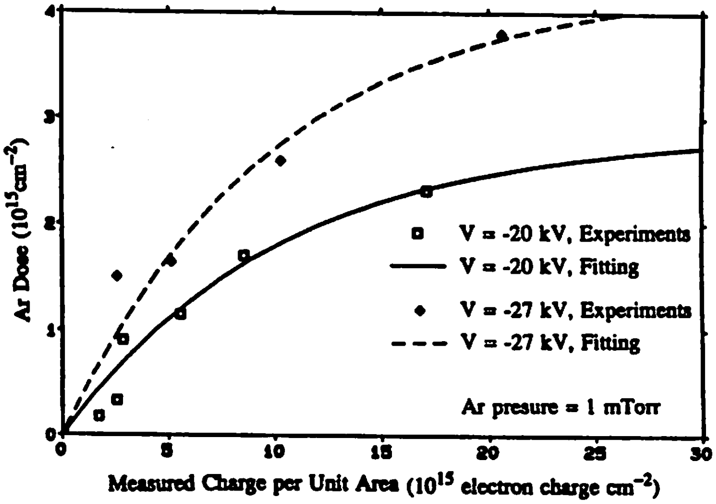


Figure 5.

The dependence of as-implanted Ar dose on the total discharge per wafer holder area. The total discharge was measured with the integrator through the current monitor. The Ar dose was measured with RBS.