

A MAGNETIC FIELD GENERATING APPARATUS AND A
PLASMA GENERATING APPARATUS FOR USE THEREWITH

The present invention relates to a plasma generating
5 apparatus, and to a magnetic field generating apparatus for
such a plasma generating apparatus.

Plasma generating apparatus utilising electron
cyclotron resonance is known, and it is known to use such
10 apparatus for the etching or deposition of the surface of
semiconductor substrates. For example, such apparatus is
disclosed in Japanese Laid open patent No. 16732/1990.

However, the known apparatus is not, for example, able
15 to provide a uniform etch or deposition rate for the wafer.

According to the present invention there is provided a
magnetic field generating apparatus for a plasma generating
apparatus, said magnetic field generating apparatus
20 comprising magnetic field generating means, a power supply
having an output connected to energise said magnetic field
generating means, a function generator, and synthesizing
means, wherein said synthesizing means is arranged to
receive an output signal from said function generator and
25 to generate a voltage signal synthesized from said function
generator output signal and a reference voltage, wherein
said generated voltage signal is applied to said power
supply which is arranged to apply an output to said
magnetic field generating means which is modulated in
30 dependence upon said generated voltage signal, and wherein
the duty cycle of the function generator is in the range
0.1 to 0.9 and its frequency is in the range 0.1Hz to 10Hz.

The modulated supply applied to the magnetic field
35 generating means enables a more uniform ion density
distribution to be obtained when the magnetic field

generated is applied in a plasma generating apparatus.

5 Preferably, said magnetic field generating means comprises at least one electromagnetic coil, and wherein said power supply is a current power supply and is arranged to supply current, modulated in dependence upon said generated voltage signal, to said coil.

10 The waveform of the output signal of said function generator may be arranged to be a square wave, a sawtooth wave, a screw thread wave, a sine wave, or the like.

15 The invention also extends to a plasma generating apparatus comprising a magnetic field generating apparatus as defined above.

20 In an embodiment of such a plasma generating apparatus, the duty cycle and the frequency of said function generator are arranged such that the ion density distribution of said apparatus is substantially flat.

25 Preferably, said magnetic field generating means comprises two coils, said power supply being arranged to energise at least one of said coils. Said power supply may be arranged to supply modulated current to each of said two coils. Alternatively, said power supply may be arranged to supply modulated current to one of said two coils, and further current supply means may be arranged to supply a further modulated current to the other of said two coils.

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The plasma generating apparatus may comprise a plasma generating chamber having a gas inlet and outlet, a waveguide communicating with the interior of the chamber for supplying microwaves, and magnetic field generating apparatus as defined above.

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The magnetic field generating means may comprise one or more magnetic coils arranged to surround at least part of said chamber.

5 Embodiments of the present invention will hereinafter be described, by way of example, with reference to the accompanying drawings, in which:-

10 Figure 1 shows a section of a plasma generating apparatus utilising a substantially conventional electron cyclotron resonance (ECR) system,

Figure 2 is a graph illustrating that the current applied to a magnetic coil of Figure 1 is a direct current,

15 Figure 3 shows a block diagram of magnetic field generating apparatus of the invention,

Figures 4(a) to 4(d) are graphs showing voltage waveforms produced by the generating apparatus of Figure 3,

20 Figures 5(a) to 5(d) are graphs showing modulated current waveforms produced by the generating apparatus of Figure 3,

Figure 6 is a graph showing the ion density distribution within a plasma generated by a conventional ECR system,

25 Figure 7 is a graph showing the ion density distribution within a plasma generated by an ECR system of the invention,

Figure 8 shows a section of a plasma generating apparatus having magnetic field generating apparatus of the invention, and

30 Figure 9 shows a section of plasma generating

apparatus having a magnetic field generating apparatus of the invention which includes two magnetic coils.

Figure 1 shows a section through a substantially conventional apparatus for generating a plasma by electron cyclotron resonance (ECR). The particular apparatus illustrated in Figure 1 is employed in semiconductor production processes, for example, for the etching and deposition of semiconductor wafers.

In the apparatus illustrated in Figure 1, a wall 4 defines a chamber having a gas inlet and two gas outlets. A waveguide 2 is arranged to apply microwaves to the chamber 4 by way of a quartz window 3. A magnetic coil 1 surrounds the part of the chamber proximate to the waveguide 2. In use, the chamber is evacuated and a gas is applied thereto through the gas inlet. Microwaves at an appropriate frequency are applied to the plasma generating chamber and at the same time the coil 1 is energised to produce a magnetic field in the plasma generating chamber. The flux density of the magnetic field, and the frequency of the microwaves are chosen such that the microwave energy and the magnetic field cause electron cyclotron resonance which generates a dense gas plasma. This plasma is focused by way of a focusing ring 5 onto a wafer 7 supported on a wafer support 6 within the chamber. The dashed lines in Figure 1 show the ion density distribution of the plasma so generated.

In a conventional device, such as shown in Figure 1, a high density plasma may be formed by rotating the magnetic field and the uniformity of the developed plasma may be improved by improving the uniformity of that rotation. The waveguide 2 generally has a rectangular cross-section and a rectangular to circular

microwave converter (not shown) is generally provided such that microwave energy in a circular mode is applied to the plasma generating chamber. However, it has been found that using circular mode microwaves causes a non-uniform plasma density within the chamber 4.

Electron cyclotron resonance is a phenomenon where the kinetic energy of the system reaches a maximum. For example, electron cyclotron resonance may be achieved when the kinetic frequency of an electron describing a rotational movement due to the magnetic field resonates with the kinetic frequency of an electron rotating under the force of the electromagnetic waves. This occurs, in other words, when the frequencies have been made to coincide, at which time the plasma generating efficiency reaches a maximum. For example, resonance will occur when the microwaves have a frequency of 2.45GHz and the magnetic field generated by the magnetic coil 1 is 875 Gauss.

The area within the chamber where resonance occurs, as described above, is limited. Therefore, in general, the ion density is high in a central portion of the plasma and reduces towards the periphery. Thus, when carrying out etching or deposition by focusing, by way of the ring 5, the plasma produced onto the wafer 6, problems do occur because of the non-uniformity of the ion density. For example, there are increasing differences in the etching rate or the deposition rate between the centre and the periphery of the wafer.

The present invention improves uniformity of etching and the like by providing a more uniform ion density distribution within the plasma generating chamber.

Figure 2 shows the direct current which is normally used to generate the magnetic field in a conventional plasma generating apparatus.

05 Figure 3 shows a block circuit diagram of a
magnetic field generating apparatus of the present
invention. The apparatus of Figure 3 is arranged to
generate a variable or modulated current $i(t)$ which is
applied to a magnetic coil to generate the magnetic
10 field for the plasma generating apparatus. It will be
seen that the circuit comprises a voltage synthesizer
or voltage combiner which is arranged to produce a
modulated voltage waveform which is synthesized from a
reference voltage and from the output voltage of a
15 function generator. The modulated voltage waveform so
formed is applied to a current power supply which is
arranged to produce a current dependent upon the
incoming voltage and thereby to produce the modulated
current $i(t)$ which is supplied to the magnetic coil.
20 The current power supply has a function whereby its
output current $i(t)$ is variable in dependence upon the
input voltage V_1 , which is normally within the range
0 to 10 volts.

25 We have seen that in a conventional apparatus,
resonance occurs in the central part of the plasma and
the plasma ion density distribution is therefore high at
its centre and reduced at the periphery as shown in
Figure 6. It will be noted that in Figure 6, the
30 effective positions of the centre C and the peripheral
edges L, R of the wafer support 6 of the apparatus of
Figure 1 are marked to illustrate the potential effect
of the ion density distribution.

35 Apparatus of the invention is arranged such that
the output of the voltage combiner or synthesizer is
applied to the input port V_1 of the current power

supply so that a modified current $i(t)$ as shown in Figures 5(a) to 5(d) is obtained. In this respect, the voltage V_1 is produced by combining a reference voltage V_3 with an output voltage V_2 from the
05 function generator. Examples of the output voltage V_2 are shown in Figures 4(a) to 4(d). Preferably, and as indicated, the voltage combiner is composed of a circuit combining several active elements.

10 The apparatus is arranged such that during the time 0 to t_1 in Figures 4(a) to 4(d), the 875 Gauss portion where resonance occurs assumes a doughnut shape. It will be appreciated that the centre portion thereof is greater than 875 Gauss. As a result, an ion density
15 distribution as shown at F in Figure 7 is achieved. In the time t_1 to t_2 illustrated in Figures 4(a) to 4(d), the centre approaches 875 Gauss and so the ion density at the centre is high and the ion density distribution is as shown at E in Figure 7. If the duty cycle for t_1
20 and t_2 and the frequency are appropriately established, an ion density distribution as illustrated at G in Figure 7 can be obtained. For this distribution curve, the uniformity of the etching rate and the uniformity of the deposition rate can be improved. In this case, the
25 duty cycle t_1/t_2 can be in the region of 0.1 to 0.9, and the frequency $1/T$ can be in the range 1/10 to 10Hz when the coil inductance is taken into account.

30 In Figure 3 the modulated current $i(t)$ is shown applied to a single magnetic coil. However, it is possible to use a plurality of coils for magnetic field generation. When there is more than one coil, the current $i_1, i_2, \dots, i_n$, applied thereto may be controlled independently. If variable currents of
35 inverted phases are utilised, the mixing effect of ion

density can be maximised.

05 With this invention, a current modulation system is
able to shift the high ion density portion where ECR
resonance occurs to a radial form in order to render the
plasma ion density uniform. It is possible to widen the
plasma ion density distribution over a uniform surface
area and thereby to improve the etching rate as well as
the deposition rate in a wafer as compared with the
10 fixed current system used in the prior art.

 It will be appreciated that Figure 8 shows the
application of the modulated current $i(t)$ to a single
coil system, whereas Figure 9 shows its application to
15 each of two separate magnetic coils.

 Particular embodiments of the invention have been
described and illustrated above. However, it will be
appreciated that modifications to, and variations in,
20 the invention as described may be made within the scope
of the appended claims.

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CLAIMS

1. A magnetic field generating apparatus for a plasma
generating apparatus, said magnetic field generating
5 apparatus comprising magnetic field generating means, a
power supply having an output connected to energise said
magnetic field generating means, a function generator, and
synthesizing means, wherein said synthesizing means is
arranged to receive an output signal from said function
10 generator and to generate a voltage signal synthesized from
said function generator output signal and a reference
voltage, wherein said generated voltage signal is applied
to said power supply which is arranged to apply an output
to said magnetic field generating means which is modulated
15 in dependence upon said generated voltage signal, and
wherein the duty cycle of the function generator is in the
range 0.1 to 0.9 and its frequency is in the range 0.1Hz to
10Hz.
- 20 2. A generating apparatus as claimed in Claim 1, wherein
said magnetic field generating means comprises at least one
electromagnetic coil, and wherein said power supply is a
current power supply and is arranged to supply current,
modulated in dependence upon said generated voltage signal,
25 to said coil.
3. A generating apparatus as claimed in Claim 1 or Claim
2, wherein the waveform of the output signal of said
function generator is arranged to be a square wave, a
30 sawtooth wave, a screw thread wave, or a sine wave.
4. A plasma generating apparatus comprising a magnetic
field generating apparatus as claimed in any preceding
claim.
- 35 5. A plasma generating apparatus as claimed in Claim 4,

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