(54) Title: IMPROVED ZONE MELT RECRYSTALLIZATION APPARATUS

(57) Abstract

The improved zone-melt recrystallization apparatus is comprised of a port system for providing a thermal barrier between the recrystallization chamber and the loader assembly. A bellows system is used to lift a plurality of pins that support a silicon wafer being recrystallized. Flexure supports are designed to constrain the motion of the pins within the desired direction of motion of the wafer.
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IMPROVED ZONE MELT RECRYSTALLIZATION APPARATUS

Background

This invention relates generally to the conversion of amorphous or polycrystalline semiconductor materials to substantially single crystal semiconductor material by a process known as zone-melting-recrystallization (ZMR).

From transistors to very large scale integration of complex circuitry on a single chip, the field of solid state electronics has been built largely upon the abundant nonmetallic element silicon. Large diameter single crystal boules of silicon are sliced into wafers on which dopants, insulators and conductors have been applied using a variety of processes. Over the past few years, a major effort has been devoted to developing a new silicon-based technology involving the preparation of very thin films of pure single crystal silicon on the order of one-half micron thick, compared to the one-half millimeter thickness of typical silicon wafers. The new technology is described as silicon-on-insulator (SOI) technology as it utilizes a thin silicon film that is supported by an insulating substrate. An efficient, reliable and economical process for producing thin film single crystal silicon has eluded researchers.
In comparison to device performance in bulk silicon, SOI promises significant advantages:

1. improved speed performance in discrete devices and circuits resulting from reduced parasitic capacitance;
2. simplified device isolation and design layout, yielding potentially higher packing densities; and
3. radiation hard circuits for space and nuclear applications.

In addition, new SOI technologies may also be utilized for three-dimensional integration of circuits.

At present, there is one mature SOI technology: silicon-on-sapphire (SOS). However, the commercial utilization of SOS has been severely limited by its high cost, relatively poor crystalline quality, and difficulty in handling and processing in comparison to bulk Si.

Recently, a new SOI technology called zone-melting recrystallization (ZMR) based on standard silicon wafers rather than sapphire crystals has exhibited the potential for displacing SOS and for utilization on a much larger scale by the semiconductor industry. The development of ZMR has been frustrated by processing problems related to the physical chemistry of the interface between the molten silicon and adjacent silicon dioxide layers which gives rise to the so-called silicon beading phenomenon during ZMR.
SOI by the ZMR technique is produced by recrystallizing a fine-grained Si film on an insulating substrate. A typical sample structure consists of a silicon wafer coated with a 1 micron thick thermally grown SiO₂ insulating layer, a half micron thick polycrystalline silicon (poly-Si) layer formed by low pressure chemical vapor deposition (LPCVD), topped by a 2 micron thick layer of SiO₂ also grown by chemical vapor deposition. The last layer forms a cover to encapsulate the polysilicon film constraining it while the film is being recrystallized.


The sample is placed on a lower graphite strip and heated to a base temperature of 1100-1300°C in an argon gas ambient. Silicon has a melting point of about 1410°C; SiO₂ remains solid at the processing temperature of the system. Additional radiant energy is typically provided by a moveable upper graphite strip heater which produces localized heating of the sample along a strip to a temperature between the two melting points. Moving like a wand, the upper heater scans across the wafer to form a moving molten zone across the sample leaving a recrystallized SOI film beneath the solid SiO₂ cap.
Existing loader assemblies for placing the wafer into the heater have a number of problems. The loading arm that transports the wafer into the ZMR chamber is subjected to excessive temperatures and thus degrades rapidly when exposed to temperatures within the chamber.

Summary of the Invention

The present invention relates to improvements in processing chambers used for zone-melt recrystallization of semiconductor wafers having SOI structures. In particular, a flexure support system is employed which controls the transport of the wafer above the platen on which the wafer rests during recrystallization. This transport assembly lowers and raises the wafer relative to the platen when the wafer is loaded or unloaded from the processing chamber.

The assembly hoists the wafer onto a loader after processing where the loader is removed from the chamber during recrystallization.

The transfer assembly is comprised of at least three pins that contact the wafer during transport. These pins are mounted on a moveable platform whose motion must be precisely controlled to prevent contact with the heating elements and prevent slippage of the wafer. The plate is preferably supported by four flexure support members which are displaced from their stress free state by a pressurized bellows which moves the plate and its attached pins up during transport of the wafer.
The plate 32 provides the force necessary to compress the bellows and lower the pins when the pressure within the bellows is released. The flexures are constructed to restrict the displacement of the pins in a linear direction and to resist radial or rotational forces exerted on the transfer assembly.

A reflective panel is placed above the upper strip heater to reflect radiation from the strip heater onto the surface of the material being recrystallized. Alternatively, the panel can be comprised of a heat absorbing material that absorbs and reradiates the energy back toward the wafer to more efficiently focus the thermal energy utilized during recrystallization. A further embodiment employs a reflective coating that lines one or more inner surfaces of the processing chamber.

A baffling system is used to thermally isolate the loader assembly from the chamber in which recrystallization occurs. A preferred embodiment utilizes a rotatable cylinder positioned between the chamber and the loader such that a slot extending through the cylinder provides access to the chamber. The cylinder is rotated to an open position permitting the insertion of the loader arm, and the wafer supported by the arm, through the slot and into the chamber. When the arm is retracted, the cylinder can be rotated to a closed position whereby the slot is prevented from transmitting heat into the loader assembly space.
The above, and other features of the invention including various novel details of construction and combination of parts, will now be more particularly described with reference to the accompanying drawings and pointed out in the claims. It will be understood that the particular improved zone-melt recrystallization apparatus embodying the invention is shown by way of illustration only and not as a limitation of the invention. The principal features of this invention may be employed in various embodiments without departing from the scope of the invention.

Brief Description of the Drawings

Figure 1 is a schematic illustration of the zone-melt recrystallization and loader apparatus of the present invention;

Figure 2 is a cross-sectional view of the double cylinder loading port of the invention;

Figure 3 is a cross-sectional view of the platen, transfer and bellows apparatus;

Figure 4 is a perspective view of the flexure support design used to control motion of the pin transfer assembly;

Figure 5 is an exploded perspective partially sectioned view of the platen assembly;

Figure 5A is an enlarged cross-sectional view of the platen heater assembly;
Figure 6 is a perspective partially sectioned view of the zone-melt recrystallization apparatus of the present invention;
Figure 7 is a side view of the upper strip heater and energy directing panel;
Figure 8 is a perspective partially sectioned view of another preferred embodiment of the platen assembly;
Figure 9 is a perspective view of another preferred embodiment of the platen assembly using tabs to suspend the wafer;
Figure 10 is a perspective view of another preferred embodiment of the platen and transfer assembly wherein wires, which extend through parallel grooves on opposite sides of the platen, can be elevated above the platen to raise and lower the wafer;
Figure 11 is a top view of another preferred embodiment of the platen and transfer assembly wherein tabs positioned about the periphery of the platen are used to elevate the wafer above the platen;
Figure 12 is a top view of another preferred embodiment of the platen and transfer assembly where portions of the platen can be elevated to permit the loader to be inserted underneath the wafer and remove it from the processing chamber; and
Figure 13 is a cross-sectional view of a radial heater assembly for the zone-melt recrystallization apparatus of the present invention.
Detailed Description

A schematic view of the zone-melt recrystallization and loader apparatus of the present invention is shown in Figure 1. The loader 12 is comprised of a pair of arms 16 that removes a silicon wafer 14 from a storage reservoir and transfers the wafer 14 through port 18 and into the chamber 10 where it is placed onto a heating element.

Figure 2 is a cross-sectional view of the port system 20. The port can be opened to permit insertion and removal of the wafer, and closed during recrystallization so that the loader is thermally isolated by the port apparatus. The port system 20 is comprised of an outer housing 26 and an inner cylinder 22 with the latter configured within the former. The inner cylinder 22 rotates to permit the closure of the port. The inner cylinder 22 has a slot 25 extending through it such that when the slot 25 is aligned with slot 23, a wafer on the loader arms can be extended through the aligned slots and into the chamber.

The port apparatus 20 can be attached to a cooling system where a coolant 24 such as a circulating water flow is passed between the inner and outer cylinders. This insures the thermal isolation of the loader 12 from the chamber 10.

Figure 3 is a cross-sectional view of the bellows and flexure support system positioned within the chamber that is used to lower or elevate the
wafer 14 relative to the platen assembly 38 during loading and unloading of the wafer from the chamber 10. The bellows 42 is supplied with a pressurized gas through a valve 44 located outside of the chamber 10 to lift pins 46 that pass through the heating system (not shown) and the platen assembly 38 to engage the wafer 14 and lift it off the platen so that the loader arms 16 can transport the wafer 14 out of the chamber 10.

This embodiment also employs a reflective material 72 that is positioned on an inner wall or surface 70 of the processing chamber. The surface 70, in one embodiment, is a window permitting viewing of the recrystallization process that, without a reflective coating, is a substantial thermal drain of the system.

There are four flexure supports 34 for the bellows assembly, one of which is shown in greater detail in Figure 4. Each flexure used to support and stabilize each corner of the plate to which the lower ends of the pins 46 are secured. Each flexure support 34 is comprised of two pairs of flexure arms. Each pair has two flexure arms 52 and 54 connected at both ends by spacial inserts 62 and 64. Each pair is then connected at a far end by a spacial insert 56. The far end of the flexure support is opposite the end at which the support is mounted onto the bellows apparatus by upper and lower connecting pins 58 and 60.
This pin lifter assembly 30 must be stable at high temperatures as it never leaves the ZMR chamber 10. The pins 46 must not perturb the temperature profile of the wafer 14 so that recrystallization is performed uniformly across the wafer with a minimum of defects. The pins 46 must move through the lower heater without touching the heating element. These pins 46 can preferably be comprised of small diameter quartz rods. The pins are mounted on a plate 32 that can be comprised of tantalum or a similar thermally stable material.

The flexure supports 34 act as a frictionless bearing and guide for the motion of the plate 32 and the attached pins 46. The upper and lower pairs of flexure arms about the central spacial insert 56 provide a small resistance to the upper and lower movement of the pins 46. The flexure supports 34 also provide a very stiff resistance to motion in the plane of the plate 32. Thus the flexure supports are designed to prevent translation or rotation of the pins 46 in the plane perpendicular to their up and down motion.

A preferred embodiment utilizes a pair of flexure supports mounted on the same set of connecting pins at a 90° angle. This embodiment operates to more effectively prevent rotation of the plate 32.

Figure 5 shows the components of a preferred embodiment of the platen assembly. Unlike the platen assembly shown in Figure 3, this embodiment
does not have holes for the pins 46, but exposes almost the entire lower surface of the wafer 14 to the lower heater. An outer platen member 100 has an inner cylindrical wall 106 having an annular groove 104 along the top edge of wall 106. One side of the platen member 100 has an opening 102 through which the contact rods 113 of the platen heating element 112 extend. An annular ring 108 is positioned between the heating element 112 and the platen member 100 to provide a thermal break between these two components. An outer annular surface 109 of the ring 108 rests on the groove 104 of the platen member 100. The heating element 112 rests on an inner peripheral surface 110 of the ring 108. An opening 111 extends through a portion of the ring which is aligned with opening 102 to provide electrical contacts to the heating element 112. An inner support ring 114 is positioned between the wafer 14 and the heating element 112. A groove 116 in the outer wall of the support ring 114 fits loosely over the heating element 112.

Figure 5A illustrates a more detailed cross-sectional view of how the components of the embodiment of Figure 5 are positioned relative to each other. The heating element 112 rests on surface 105. A thermal break or space 103 is located between the support ring 114 and the annular ring 108.

Figure 6 illustrates, in a partially sectioned perspective view, the configuration of the three
heating elements and the transfer assembly relative to the platen 100 and wafer 14 supported thereon.

A lower heater 160, preferably comprised of a single graphite element, is positioned between the plate 32 that is supported by flexures 34. The flexures 34 are supported by a base plate 162. A heat shield (not shown) can be positioned between the plate 32 and heating element 160 to thermally isolate the bellows and flexure support systems.

Holes 170 within the heating element 160 permit passage of the pins 46 so that they can be raised to contact and lift the wafer 14 after processing. The strip heater 164 is clamped to a frame 166 so that the heating element 164 can be translated relative to the wafer 14. The outer peripheral edge of the wafer rests on support ring 114 which is heated by element 112.

Figure 7 illustrates a side view of the strip heater 164 extending over the wafer 14 wherein a panel 170 is used to direct thermal radiation 172 that emanates from heater 164 away from the wafer 14 back onto the wafer thereby widening slightly the melt-zone on the wafer 14.

Figure 8 illustrates another preferred embodiment of the platen assembly where the support ring 140 has an opening 152 having sufficiently large dimensions to permit the loader arm 150 to be inserted through opening 152 and under the wafer 14 so that the wafer need not be lifted off the ring 40 by a separate transfer assembly.
Figure 9 illustrates a further embodiment where three or more tabs 154 extending inwardly from ring 40 are used to support the wafer 14. This structure exposes most of the wafer 14 to the lower heater thereby minimizing thermal gradients at the rim of the wafer.

Figure 10 illustrates another preferred embodiment of the transfer assembly where parallel wires 122 and 124 extend through grooves 126 and 128 in the upper surface of support ring 120. The wires are spaced so that they can lower and raise the wafer 14 to permit the loader to insert or remove the wafer from the chamber 10.

Figure 11 illustrates another preferred embodiment of the platen and transfer assemblies where a number of tabs 80, which are manipulated by pins 82, that extend under the edge 86 of the wafer 14. The pins can be raised and lowered relative to the platen 84 so that the wafer can be removed from the chamber.

Figure 12 illustrates a further preferred embodiment of the platen and transfer assemblies wherein two stationary portions of the platen 90 are separated by moveable portions 92 and 94 that can be raised and lowered relative to the stationary elements 90 to raise and lower the wafer 14.

The embodiments of the platen shown in Figures 8-12 result in systems for loading wafers into the chamber without the need for pins 46 which extend through the lower heater. Without the holes 170 in
the lower heater 160 that are positioned directly beneath the wafer, a more uniform heat distribution is possible. Even with the more uniform heat distribution resulting from the embodiments of Figures 8-12, there also exists a radial disparity in the heat distribution generated by the lower heater which is only partially offset by the circular platen heater 112.

Figure 13 illustrates another preferred embodiment in which one or more circular heaters 142 and 144 are positioned concentrically within the platen heater 36. This circular array of heating elements operates to correct for any uneven radial distribution of heat across the wafer.

Figure 14 illustrates another preferred embodiment in which the single element lower graphite heater 160 of Figure 6 is replaced by a multiple element array comprised of a grid 180 of graphite strips or wires 184. The array forms an x-y grid in which each heater can be individually controlled at contact points 182. With this arrangement, non-uniformities in the temperature distribution across the wafer could be compensated by applying different power levels to each heater.
1. A system for zone melt recrystallization of a semiconductor material comprising:
   a processing chamber to zone melt recrystallize a semiconductor material;
   a platen within the chamber to support the semiconductor material during zone-melt recrystallization of the material;
   a first heater that is stationary relative to the material and which heats said material to a temperature below a melting temperature of the material;
   a second heater that is translatable relative to the material to heat a portion of said material above the melting temperature of the material such that a translatable melt zone is generated to continuously melt and recrystallize the material;
   a transfer assembly to vertically translate the material relative to the platen within the chamber;
   a controller to control translation of the transfer assembly from outside the chamber; and
   a loader to load the material into the chamber and onto the transfer assembly.

2. The system for zone-melt recrystallization of Claim 1 further comprising a third heater positioned adjacent the platen to heat a
portion of the material contacting the platen to a temperature below a melting temperature of the material.

3. The system for zone-melt recrystallization of Claim 1 further comprising a panel positioned on one side of the second heater opposite the material to be recrystallized such that the panel directs heat emitted by the second heater towards the material.

10 4. The system for zone-melt recrystallization of Claim 3 wherein said panel comprises a reflective material.

5. The system for zone-melt recrystallization of Claim 3 wherein said panel comprises a thermally absorbing material such that radiation from the second heater is absorbed and transmitted towards the material being recrystallized.

6. The system for zone-melt recrystallization of Claim 1 wherein said processing chamber further comprises an inner surface adjacent the second heater and the material to be recrystallized, and a reflective material extending along the inner surface of the chamber such that heat radiated away from the first and second heaters
toward the reflective material is reflected towards the platen.

7. The system for zone-melt recrystallization of claim 1 wherein said transfer assembly comprises a bellows.

8. The system for zone-melt recrystallization of claim 1 wherein said transfer assembly comprises a plurality of pins extending vertically through openings in the first heater.

9. The system for zone-melt recrystallization of claim 8 further comprising a flexure support system secured to one end of each pin to linearly direct a displacement of the pins.

10. Apparatus for transporting a semiconductor material within a chamber for zone-melt recrystallization comprising:
    a plurality of at least three pins for supporting a semiconductor material;
    a plate for mounting said pins;
    a bellows apparatus for raising and lowering said pins above and below a heating element; and
    a flexure support system for confining the motion of the pins in a single direction.
11. The apparatus of Claim 10 wherein said pins are comprised of quartz rods.

12. The apparatus of Claim 10 wherein said plate is comprised of tantalum.

13. The apparatus of Claim 10 wherein said bellows are actuated by a high pressure gas flow.

14. The apparatus of Claim 10 wherein said flexure support system is comprised of a pair of arms attached at one end by a spacial insert and wherein one arm is connected at the opposite end to the plate, and wherein the other arm is connected to a stationary lower support element.

15. The apparatus of Claim 14 wherein said flexure support system operates as a frictionless bearing.

16. The apparatus of Claim 14 wherein said pair of arms is mounted with a second pair of arms configured at a 90° angle from said first pair of arms.

17. The apparatus of Claim 14 wherein each arm is comprised of a pair of flexible members connected at both ends by a spacial insert.
18. A baffle system for loading semiconductor wafers into a heating chamber for zone-melt recrystallization of the wafer comprising:
   a chamber enclosing an apparatus for zone-melt recrystallization of semiconductor wafers;
   a loader for supporting the wafer and transporting said wafer into the chamber; and
   a rotatable elongated outer cylinder with a slot extending therethrough such that the loader, with a wafer supported by the loader can be inserted into the chamber through the slot when the cylinder is rotated to an open position and such that heat generated by the chamber is isolated from the loader when the cylinder is rotated to a closed position.

19. The baffle system of Claim 18 further comprising an inner elongated cylinder that is rotatable within said first cylinder and having a slot extending therethrough such that when the slots of the outer and inner cylinders are approximately aligned in an open position the loader can transport a wafer into the chamber through said slots; and such that the slots of the inner and outer chambers can be rotated out of alignment to a closed position to isolate the loader from heat generated by chamber.
20. The system for zone-melt recrystallization of Claim 1 wherein the first heater comprises a grid of independently controlled heating elements.
# INTERNATIONAL SEARCH REPORT

## I. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both National Classification and IPC

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  - "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"Z" document member of the same patent family

## IV. CERTIFICATION

Date of the Actual Completion of the International Search: 23rd February 1989

Date of Mailing of this International Search Report: 23 Mar 1989

International Searching Authority: EUROPEAN PATENT OFFICE

Signature of Authorized Officer: P.C.G. VAN DER PUTTEN

Form PCT/ISA/210 (second sheet) (January 1985)
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<td>silicon on square-shaped fused quartz&quot; pages 2986-2988 see page 2986, figure 1</td>
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<td>US, A, 4097226 (ERIKSON et al.) 27 June 1978 see abstract; column 5, lines 12-32; figure 4</td>
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ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. US 8804043
SA 25503

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
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