

## **WAFER BOATS FOR SUPPORTING SEMICONDUCTOR WAFERS IN A FURNACE**

### **CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 63/044,698, filed 26 June 2020, which is incorporated herein by reference in its entirety.

### **FIELD OF THE DISCLOSURE**

[0002] The field of the disclosure relates to semiconductor wafer boats for supporting semiconductor wafers and, more particularly, semiconductor wafer boats for use in the heat-treatment of semiconductor wafers in a furnace.

### **BACKGROUND**

[0003] Semiconductors wafers are commonly heat-treated at high temperatures (i.e., annealed) to achieve certain desirable characteristics. For example, annealing may be used to create a defect free layer of silicon on the wafer. The high temperature annealing process is typically carried out in a vertical furnace which subjects the wafers to temperatures above 1100°C (e.g., between about 1200°C and about 1300°C).

[0004] A plurality of semiconductor wafers may be supported in the vertical furnace by a wafer boat or “rack”. The wafer boat includes one or more supports on which the semiconductor wafer rests. During exposure to the high temperatures, particularly temperatures above 1100°C, the wafers become temporarily more plastic, i.e., the yield strength of the wafers decreases. Contact areas on the wafer where the wafer is supported may undergo slip due to local gravitational and thermal stresses. Slip may introduce contaminants into the wafer. In addition, excessive slip may lead to plastic deformation of the wafers,

leading to production problems, such as photolithography overlay failures causing yield losses in device manufacture.

[0005] The supports aim to hold the semiconductor wafer while minimizing local gravitational and thermal stresses to prevent slip and plastic deformation while the wafers are being heat-treated. Conventionally, a wafer boat used in a vertical furnace includes three or more rods. The rods have laterally extending fingers lying generally in a common horizontal plane. This configuration is conventional and generally adequate for heating wafers with smaller diameters such as 200 mm or less. Larger diameter wafers (e.g., greater than 200 mm) are subjected to greater local gravitational and thermal stress than smaller diameters wafers. Such larger diameter wafers are conventionally loaded onto support rings which provide a greater surface area for supporting the wafers. The support rings increase the time for loading and unloading of the semiconductor wafers onto the wafer boat.

[0006] A need exists for wafer boats that include supporting structures that reduce local gravitational and thermal stress in order to limit the incident of slip while supporting semiconductor wafers as they are subjected to high temperatures during an annealing process and for wafer boats that are capable of relatively high throughput for loading and unloading wafers.

[0007] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

## SUMMARY

[0008] One aspect of the present disclosure is directed to a wafer boat for supporting a plurality of semiconductor wafers in a furnace. The wafer boat includes a vertical rod and a set of fingers that extend radially inward from the vertical rod. Each finger of the set includes an elongated segment that extends from the vertical rod. A contact protuberance is disposed on the elongated segment toward a distal end of the finger for contacting and supporting a semiconductor wafer. At least a portion of the contact protuberance is raised with respect to the elongated segment.

[0009] Various refinements exist of the features noted in relation to the above-mentioned aspects of the present disclosure. Further features may also be incorporated in the above-mentioned aspects of the present disclosure as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to any of the illustrated embodiments of the present disclosure may be incorporated into any of the above-described aspects of the present disclosure, alone or in any combination.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Fig. 1 is a perspective view of a wafer boat;

[0011] Fig. 2 is a top view of the wafer boat showing contact protuberances;

[0012] Fig. 3 is a detailed view of a contact protuberance shown in Fig. 2;

[0013] Fig. 4 is a detailed view of another embodiment of a contact protuberance; and

[0014] Fig. 5 is a probability plot of the slip length for a first and second length of a contact protuberance.

[0015] Corresponding reference characters indicate corresponding parts throughout the drawings.

#### DETAILED DESCRIPTION

[0016] An example wafer boat for supporting a plurality of semiconductor wafers in a vertical furnace is indicated generally at “10” in Fig. 1. The wafer boat 10 supports the plurality of semiconductor wafers during a high temperature heat-treatment process (also referred to herein as an “anneal”). The wafer boat 10 includes at least one vertical rod 12 (and typically three or more rods) that is coupled to a top 14 and a base 16 of the wafer boat 10. The wafer boat 10 includes a longitudinal central axis  $Y_{10}$  which extends from the top 14 to the base 16. The vertical rod 12 is arranged a distance  $D_1$  from the longitudinal central axis  $Y_{10}$  (Fig. 1).

[0017] The illustrated wafer boat 10 includes three vertical rods 12 and, in particular, a central rod 18 and two forward rods 20. Each of the vertical rods 12 is arranged on a first circle  $C_1$  (Fig. 2) centered about the longitudinal central axis  $Y_{10}$  and having a radius  $R_1$ . The two forward rods 20 are spaced apart about the longitudinal central axis  $Y_{10}$  by a first angle  $\alpha_1$ . The central rod 18 is spaced an equal circumferential distance between the two forward rods 20, such that the central rod 18 is spaced about the longitudinal central axis  $Y_{10}$  at a second angle  $\alpha_2$  relative to each of the two forward rods 20. The two forward rods 20 are spaced apart by the first angle  $\alpha_1$  such that an entrance 24 (Fig. 1) is defined between the two forward rods 20. The first angle  $\alpha_1$  may be any suitable angle such that the entrance 24 is sized to allow a semiconductor wafer to pass through the entrance 24 and arranged within an interior space 26 of the wafer boat 10. For

example, the first angle  $\alpha_1$  may be  $180^\circ$  or more and the second angle  $\alpha_2$  may be  $90^\circ$  or less.

[0018] The wafer boat 10 includes fingers 30 that extend radially inward from the vertical rods 12 for supporting semiconductor wafers (i.e., the boat does not include support rings for supporting wafers). The two forward vertical rods 20 include a first and a second set 36, 38 of fingers 30, respectively. The central vertical rod 18 includes a third set 40 of the fingers 30. The first set 36 of fingers 30 extend along a first finger axis  $A_{36}$ , the second set 38 of fingers 30 extend along a second finger axis  $A_{38}$ , and the third set 40 of fingers extends along a third finger axis  $A_{40}$ . Each finger axis  $A_{36}$ ,  $A_{38}$ ,  $A_{40}$  extends from a proximal end 32 of the finger 30 to a distal end 34 of the finger 30. The proximal end 32 of the finger 30 is proximate to the vertical rods 12 and the distal end 34 of the finger 30 is disposed in the interior space 26 of the wafer boat 10. The fingers 30 may be formed integrally with the vertical rods 12, e.g., cuts may be made in an elongate one-piece structure to form the fingers 30. Alternatively, the fingers 30 may be formed separately and coupled to the vertical rods 12.

[0019] The finger axes  $A_{36}$ ,  $A_{38}$  of the first and second sets 36, 38 of fingers 30, each extends over a chord  $X_{36}$ ,  $X_{38}$  of the first circle  $C_1$ . The chords  $X_{36}$ ,  $X_{38}$  do not intersect the longitudinal central axis  $Y_{10}$  of the wafer boat 10 (i.e., the first and second sets 36, 38 of fingers are not centered such that they point to the longitudinal central axis  $Y_{10}$ ). The finger axis  $A_{40}$  of the third set 40 of fingers 30 extends over a chord  $X_{40}$  of the first circle  $C_1$  that intersects the longitudinal central axis  $Y_{10}$ .

[0020] A group 42 of fingers 30 that extend from each of the vertical rods 12 lies in the same, generally horizontal, plane to enable the group 42 of fingers 30 to support a semiconductor wafer. The distal ends 34 of the fingers 30 in the group 42 lie on a second circle  $C_2$ . The second circle  $C_2$  has a radius  $R_2$

and is centered on the longitudinal central axis  $Y_{10}$ . The radius  $R_2$  extends from the distal ends 34 of the fingers 30 to the longitudinal central axis  $Y_{10}$  of the wafer boat 10. In the illustrated embodiment, each of the distal ends 34 of the fingers 30 in the group 42 is arranged at an equal circumferential distance from each of the other distal ends 34 of the other fingers 30 in the group 42. For example, in the illustrated embodiment including the first, second, and third sets 36, 38, 40 of fingers 30, the distal ends 34 of each of the first, second, and third sets 36, 38, and 40 of fingers 30 are each spaced apart by an angle  $\beta$  defined on the second circle  $C_2$  centered on the longitudinal central axis  $Y_{10}$ . In the illustrated embodiment, the angle  $\beta$  is  $120^\circ$ .

[0021] With reference to Fig. 3, each of the fingers 30 includes an elongated segment 50 that extends from the vertical rod 12 and a contact protuberance 52 disposed on the elongated segment 50 towards the distal end 34 of the finger 30. The contact protuberance 52 contacts and supports a semiconductor wafer. The contact protuberance 52 is raised with respect to the elongated segment 50. The contact protuberance 52 has a first end 54, a second end 56, and a longitudinal contact protuberance axis  $A_{52}$  that extends through the first and second ends 54, 56 of the contact protuberance 52. The contact protuberances 52 may be used to support any diameter of wafer including 200 mm diameter wafers, 300 mm diameter wafers and/or wafer that are greater than 300 mm in diameter.

[0022] The illustrated contact protuberances 52 are rounded (e.g., increases in height from each side to an apex that extends along the axis  $A_{36}$ ). The rounded contact protuberance 52 includes a surface that is generally cylindrical in shape. Each contact protuberance 52 includes a length  $L_1$  extending along the longitudinal contact protuberance axis  $A_{52}$  and a width  $W_1$  perpendicular to the length  $L_1$ . The wafer rests on the rounded contact protuberance 52 generally along the longitudinal contact protuberance axis  $A_{52}$ .

[0023] In some embodiments, the contact protuberance 52 has a width  $W_1$  of 3 mm to 20 mm, a length  $L_1$  of 10 mm to 50 mm, and the distance from the contact protuberance 52 to a longitudinal central axis  $Y_{10}$  of the wafer boat is from 75 mm to 125 mm. In some embodiments, the contact protuberance 52 has a width  $W_1$  of 8 mm, a length  $L_1$  of 30 mm, and the distance from the contact protuberance 52 to a longitudinal central axis  $Y_{10}$  of the wafer boat 10 is 100 mm.

[0024] In some embodiments such as the embodiment shown in Fig. 4, the contact protuberance 52 is flat. The components shown in Fig. 4 that are analogous to those of Figs. 1-3 are designated by the corresponding reference number of Figs. 1-3 plus "100" (e.g., part 52 becomes 152). The flat contact protuberance 152 includes a contact surface having a surface area that is defined by the length  $L_1$  extending along the longitudinal contact protuberance axis  $A_{152}$  and the width  $W_1$ , perpendicular to the length  $L_2$ . The surface, in its entirety, is generally in contact with the semiconductor wafer resting on the flat contact protuberance 152.

[0025] In some embodiments, the contact protuberance 152 has a width  $W_1$  of 3 mm to 20 mm, a length  $L_1$  of 10 mm to 50 mm, and the distance from the contact protuberance 152 to a longitudinal central axis  $Y_{10}$  of the wafer boat 10 is from 75 mm to 125 mm. Alternatively or in addition, the contact protuberance 152 has a width  $W_1$  of 8 mm, a length  $L_1$  of 25 mm, and the distance from the contact protuberance 152 to a longitudinal central axis  $Y_{110}$  of the wafer boat is 100 mm. The wafer rests on the flat contact protuberance 152 such that the wafer is in contact with the entirety of the surface area.

[0026] Alternatively, the protuberance 52 may be generally dome shaped with the semiconductor wafer resting on a relatively small, point-like, area.

[0027] The wafer boats of the present disclosure have several advantages compared to conventional wafer boats. Contact protuberances reduce the contact area between the wafer boat and the wafer which reduced slip. Equally circumferentially spaced contact protuberances promote even distribution of the wafer weight onto each of the contact protuberances. As known to one skilled in the art, the peak stress in the wafer is sensitive to machining inaccuracies of the contact protuberances which can cause uneven loading. In embodiments where the contact protuberance is rounded, dimensions and shape of the rounded contact protuberance minimize the effect of potential machining inaccuracies to limit uneven loading the of the wafer weight.

### EXAMPLES

[0028] The processes of the present disclosure are further illustrated by the following Examples. These Examples should not be viewed in a limiting sense.

#### **Example 1: Probability Plot of Slip Length**

[0029] Sets of silicon wafers were annealed using wafer boats including rounded contact protuberances having a length of 10 mm and another set was annealed in wafer boat including rounded contact protuberances having a length of 20 mm. Probability slip length, at a confidence interval of 95%, was determined for wafer boats having cylindrical contact protuberances for each of the contact protuberance lengths of 10 mm and 20 mm (Fig. 5). As shown in Fig. 5, the 20 mm length contact protuberance resulted in a reduced slip length relative to the 10 mm contact protuberance.

[0030] As used herein, the terms “about,” “substantially,” “essentially” and “approximately” when used in conjunction with ranges of dimensions, concentrations, temperatures or other physical or chemical properties

or characteristics is meant to cover variations that may exist in the upper and/or lower limits of the ranges of the properties or characteristics, including, for example, variations resulting from rounding, measurement methodology or other statistical variation.

[0031] When introducing elements of the present disclosure or the embodiment(s) thereof, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," "containing," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. The use of terms indicating a particular orientation (e.g., "top," "bottom," "side," etc.) is for convenience of description and does not require any particular orientation of the item described.

[0032] As various changes could be made in the above constructions and methods without departing from the scope of the disclosure, it is intended that all matter contained in the above description and shown in the accompanying drawing[s] shall be interpreted as illustrative and not in a limiting sense.