May 14, 1968 D. M. HARRIS 3,383,497

ELECTRIC RESISTANCE HEATERS

Original Filed Dec. 2, 1964 4 Sheets-Sheet 1

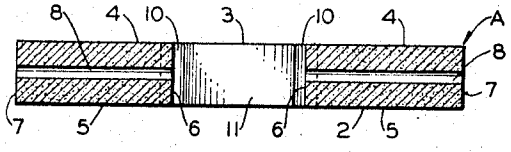


FIG. 2

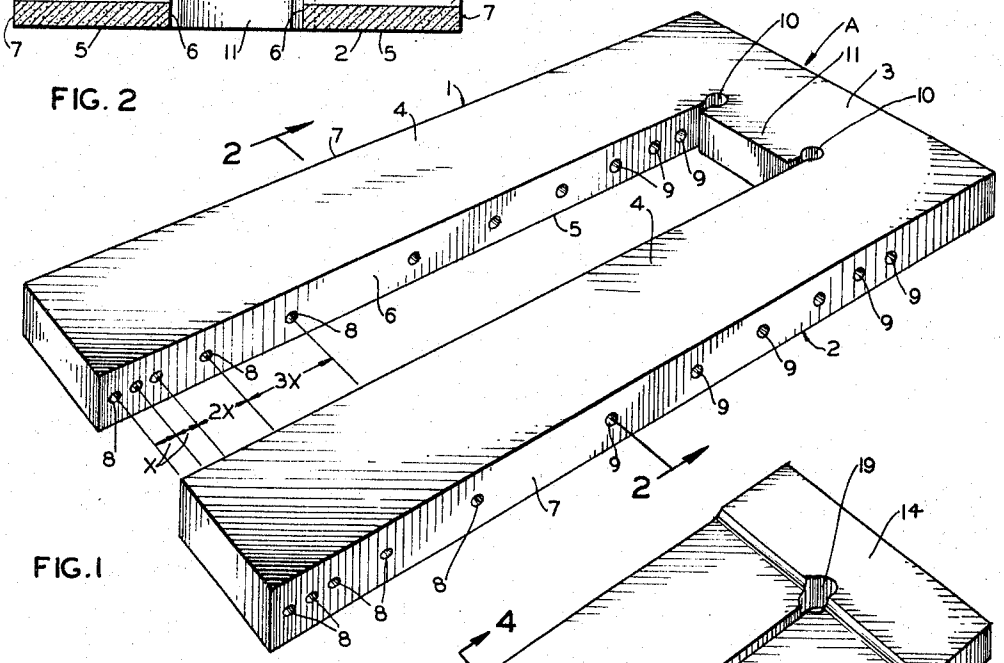


FIG. 1

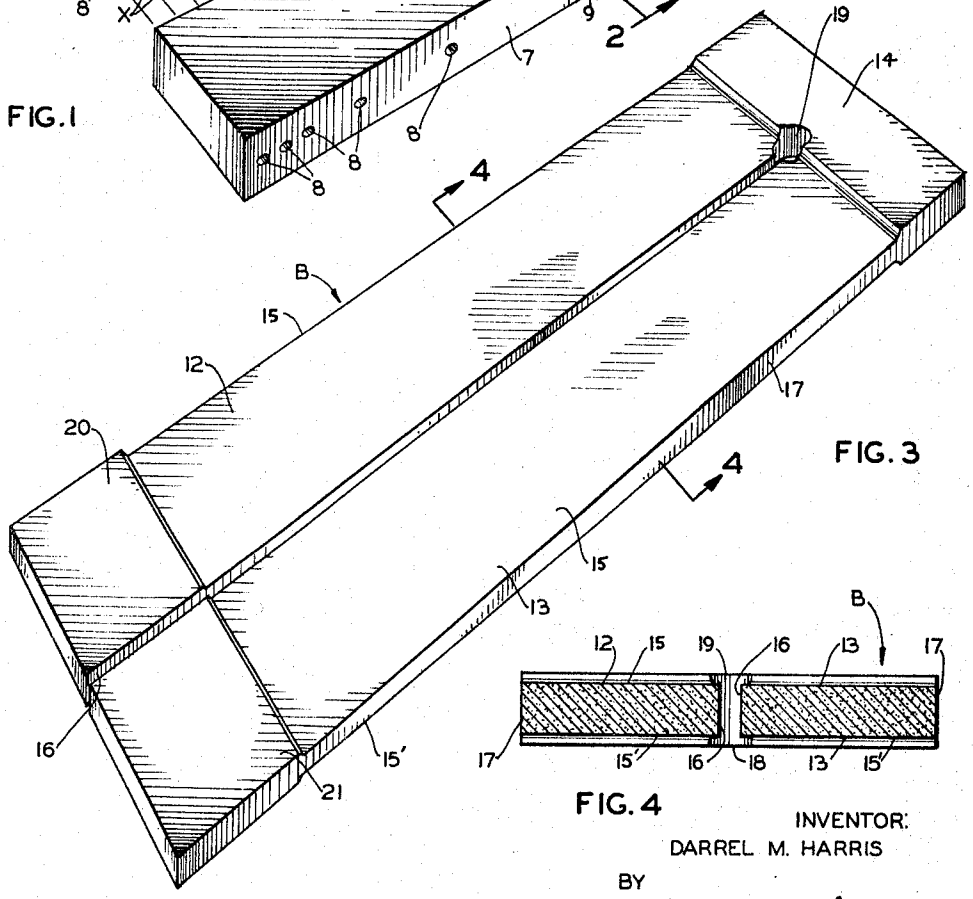


FIG. 3

FIG. 4

INVENTOR:
DARREL M. HARRIS
BY
Robert J. Schaap
ATTORNEY

TEMPERATURE CHACTERISTICS OF UNCOMPENSATED HEATER
TEMPERATURE VS BRIDGE LENGTH

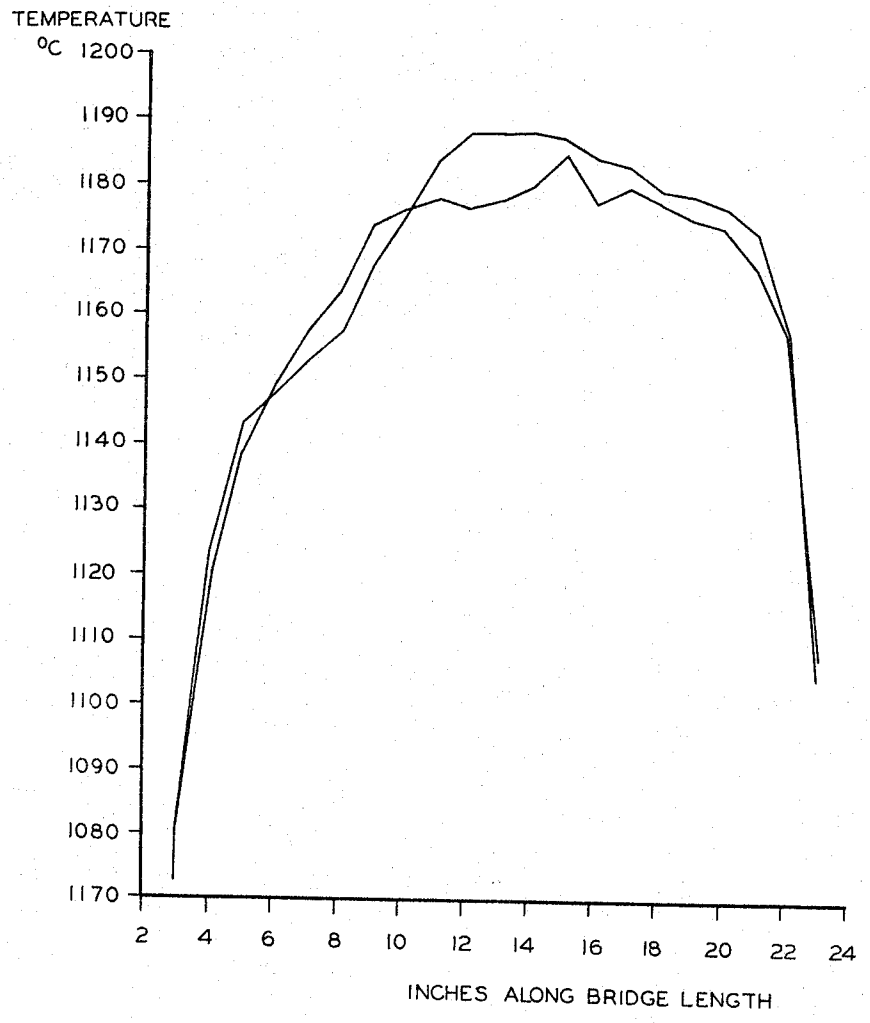


FIG. 5

INVENTOR
DARREL M. HARRIS
BY
Robert J. Schaap
ATTORNEY

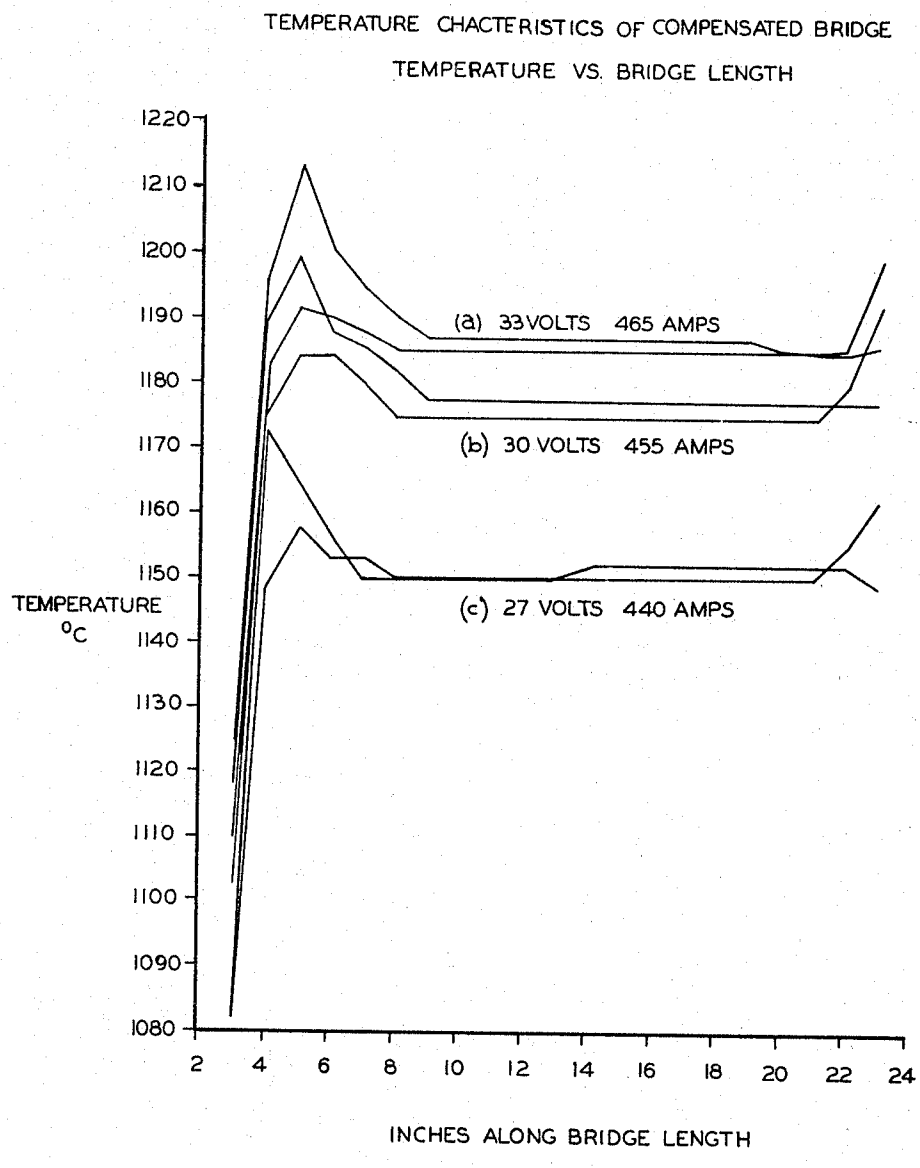


FIG. 6

INVENTOR
DARREL M. HARRIS
BY
Robert J. Schaap
ATTORNEY

ELECTRIC RESISTANCE HEATERS

Original Filed Dec. 2, 1964 4 Sheets-Sheet 4

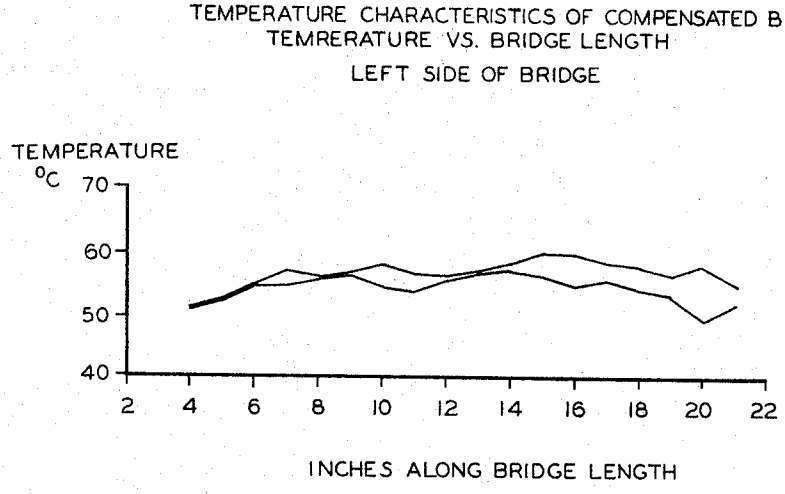


FIG. 7

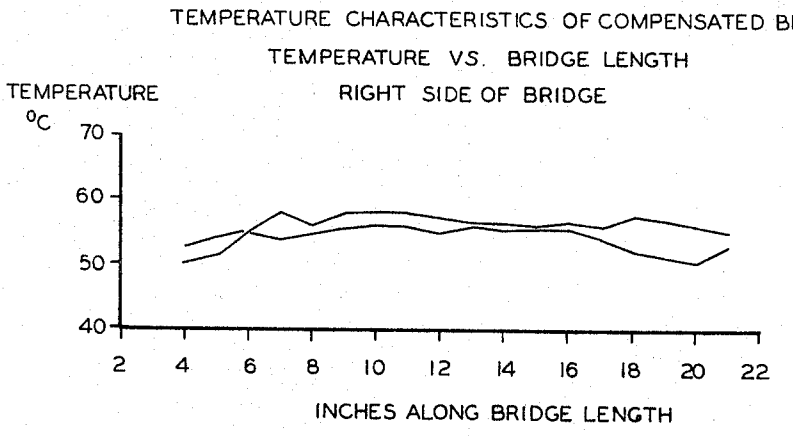


FIG. 8

INVENTOR
DARREL M. HARRIS
BY
Robert J. Schaap
ATTORNEY

United States Patent Office 3,383,497
Patented May 14, 1968

3,383,497

ELECTRIC RESISTANCE HEATERS

Darrel M. Harris, Kirkwood, Mo., assignor to Monsanto Company, St. Louis, Mo., a corporation of Delaware

Original application Dec. 2, 1964, Ser. No. 415,363, now Patent No. 3,351,742, dated Nov. 7, 1967. Divided and this application Feb. 3, 1967, Ser. No. 641,389
5 Claims. (Cl. 219—553)

ABSTRACT OF THE DISCLOSURE

A graphite heating element for epitaxial deposition furnaces which comprises a pair of legs connected by a bight portion, each of the legs is tapered from a point centrally of its end so that it is thicker in the center. The taper is such that the cross sectional area provides uniform electric resistance and uniform heat distribution throughout. The bight portion is substantially thicker than each of the legs and includes a larger central aperture at the point of connection with each of the legs. A second modification is also provided and attains uniform electric resistance characteristics and uniform heat distribution by selectively drilling apertures transversely through the legs so that the apertures are concentrated near each of the ends of the legs.

This application is a division of copending application, Ser. No. 415,363, filed Dec. 2, 1964, now Patent No. 3,351,742, dated Nov. 7, 1967.

This invention relates in general to certain new and useful improvements in heating devices and more particularly to an improved method for maintaining temperature uniformity across the length of electric resistance heaters.

In recent years, semiconductor devices such as silicon controlled rectifiers have found widespread use in the electronics industry. These solid state rectifiers, such as the silicon controlled rectifiers are often formed by depositing an epitaxial silicon film on wafers formed of generally high purity silicon. The silicon wafers are normally placed upon a graphite heating element which forms part of an epitaxial silicon furnace and are heated to a temperature where free silicon is deposited on the wafer and becomes bonded to the surface of the wafer. These wafers are then further processed by conventional methods and used in the manufacture of solid state devices such as silicon controlled rectifiers.

In the recent years, it has become a common practice to employ resistance heating elements formed of graphite in these epitaxial silicon furnaces. These heating elements are generally U-shaped in horizontal cross section and consist of a pair of legs which are connected by a bight portion. The legs are generally provided with terminal connectors at their free ends or the ends remote from the bight portion for ultimate connection to a suitable source of electrical current. A suitable amount of electrical current is then passed through the heating element to heat the element to the desired reaction temperature. However, by reason of the fact that graphite is suitable for use as an electrical heating element, it inherently includes a certain amount of internal resistance which interferes with the passage of electrical current. Therefore, as the electrical current traverses the length of each of the legs in the heating element, a slight voltage drop is developed across the entire length of the heating element and the temperature at the ends of the legs which are connected to the bight portion suffer a temperature drop. The terminal connectors are normally secured in clamps which are water cooled. Consequently, there is a rather large heat loss near the terminal ends of the legs which are secured

to the clamps. As a result thereof, the ends of the legs are cooler than the center portion thereof with the result of a non-linear temperature distribution across the legs forming part of the graphite heater. Moreover, there are local hot spots or heat concentrations along portions of the legs forming part of the heater.

As a result of this occurrence, graphite heating elements have been seriously limited in their effective length, and consequently, the resultant capacity of epitaxial silicon furnaces and similar types of furnaces have been greatly hampered.

It is therefore, the primary object of the present invention to provide an electric resistance heating element which has compensated resistance characteristics for maintaining uniform temperature distribution throughout its effective length.

It is another object of the present invention to provide an electric resistance heating element of the type stated which is highly efficient and relatively inexpensive to manufacture.

It is a further object of the present invention to provide a heating element of the type stated which can be conveniently and inexpensively modified for accommodation to the conditions of a particular epitaxial silicon furnace.

It is also an object of the present invention to provide a method of selectively altering the cross sectional area of selected portions of a heating element to maintain desired resistance characteristics throughout its effective length for attaining uniformity of temperature.

With the above and other objects in view, my invention resides in the novel features of form, construction, arrangement, and combination of parts presently described and pointed out.

In the accompanying drawings:

FIGURE 1 is a perspective view of a heater constructed in accordance with and embodying the present invention;

FIGURE 2 is a vertical sectional view taken along lines 2—2 of the heater of FIGURE 1;

FIGURE 3 is a perspective view of a modified form of heater constructed in accordance with and embodying the present invention;

FIGURE 4 is a vertical sectional view taken along line 4—4 of FIGURE 3;

FIGURE 5 is a graph of the temperature characteristic of an uncompensated bridge showing temperature versus bridge length;

FIGURE 6 is a graph of the temperature characteristic of a bridge compensated by selectively drilling apertures in accordance with the method of the present invention, showing temperature versus bridge length for various power settings;

FIGURE 7 is a graph of the temperature characteristic of a modified form of compensated bridge constructed in accordance with the present invention and showing temperature versus bridge length for one leg of the bridge; and

FIGURE 8 is a graph of the temperature characteristic of the bridge of FIGURE 7 showing temperature versus bridge length for the other leg of the bridge.

Generally speaking, the present invention is concerned with graphite heating elements, and a method of altering the cross sectional area along selected portions of the length of graphite heaters. The manufacture of epitaxial silicon wafers has always been a costly process inasmuch as it is necessary to maintain a high degree of purity, and uniform crystal structure. However, it has been extremely difficult to maintain uniform crystal structure and moreover, to maintain uniformity of thickness of an epitaxial layer deposited on a silicon wafer. Various modifications of epitaxial silicon furnaces were performed and alternate

methods were used in order to attempt to obtain epitaxial layers on silicon wafers. However, the prior art was completely devoid of an explanation for non-uniform thicknesses of epitaxial silicon layers. It has been found in connection with the present invention, that film quality can be maintained with a high degree of control by maintaining a substantially uniform temperature throughout the entire length of the graphite heater. Mooreover, uniformity of temperature in the epitaxial desposition process produces films with substantially uniform resistivities. It has also been found that uniformity of temperature aids in control of film thickness.

In accordance with the present invention, it has been found that by removing selected portions of the graphite heater at selected areas along its length by drilling small apertures, it is possible to reduce the cross sectional area of such portions and thereby alter the resistance characteristics of these particular areas. In this manner, it is possible to maintain a substantially non-uniform electrical resistance characteristic thruoghout the entire length of the heater and this, in turn, provides substantially uniform temperature distribution throughout the effective length of the heater.

The present invention also provides a modified form of graphite heater with substantially widened legs. Moreover, the legs are of the modified form of heater. The legs do not have a uniform cross sectional thickness but have a smaller cross sectional thickness at their transverse ends, that is the free ends which are adapted for ultimate attachment to a furnace. In this manner, it is possible to maintain a substantially non-uniform electrical resistance characteritic by adjusting the thickness of the bridge legs so that it is possible to maintain a substantially uniform temperature distribution for the effective length of each of the legs.

In the present invention, the effective length of the legs of the heater refers to that portion of a length of a leg which presents a usable surface for accommodation of silicon wafers.

Referring now in more detail and by reference characters to the drawings which illustrate practical embodiments of the present invention, A designates a graphite heater or so-called "bridge" generally comprising a pair of horizontal legs **1, 2** which are connected by a bight portion **3**. The legs **1, 2** are provided with top and bottom faces **4, 5** respectively, interior faces **6** and exterior faces **7**.

Each of the legs **1, 2** is drilled near the free end thereof to provide small apertures **8** for selectively reducing the cross sectional area of each of the legs **1, 2**. The apertures **8** extend the width of each of the legs **1, 2**, that is from the exterior face **7** to the interior face **6**. Moreover, the apertures **8** are sufficiently small, in the range of approximately 1/16 inch diameter in order to eliminate any effect on the structural characteristics of the heater A. It has been found that by selectively drilling the apertures **8** at a point midway between the upper and lower faces of each of the legs **1, 2** there is practically no reduction in internal strength. In many cases, it has been found that superior results are obtained when the apertures **8** are separated by increasingly smaller distances closer to the free end of the legs **1, 2**. Thus, the spacing between each of the apertures **8** is increased as the distance of the aperture from the free end of the legs **1, 2** increases in the form of a geometric proportional increase.

It is not necessarily preferable to space the apertures **8** in the form of a geometric progression. In some cases, depending upon the particular graphite heater, it has been found that suitable results are obtained when the apertures **8** are located in groups of variable spacings or of constant spacings. For example, in the graphite heater illustrated in FIGURE 1, it was found that a group of apertures spaced from each other by a distance X, followed by a second group of apertures spaced from each other by a distance of 2X, followed by a third group of apertures spaced from each other by a distance of 3X was found to produce very suitable results. The method of selectively placing the apertures is hereinafter described in detail.

It is also possible, but not absolutely necessary to provide a similar set of apertures **9** near the ends of the legs **1, 2** which are formed with the bight **3**, substantially as shown in FIGURE 1. Again, each of the apertures **9** is placed midway between the top and bottom faces of the legs **1, 2** and is located so that it can present a substantially uniform temperature distribution across the length of the legs **1, 2**. It has been found that by selectively drilling the apertures in this manner, the strength of the entire heater A is maintained, and yet the cross sectional area is adjusted so that a substantially uniform temperature distribution is maintained throughout its entire length.

It is also known that the current passing through the legs **1, 2** and through the bight portion **3** has a tendency to travel through the shortest current path in materials such as the graphite, from which the heating element A is formed. For this reason, the conventional heaters usually experience large current densities around the inner point of connection between the bight **3** and the legs **1, 2**. This type of condition creates a substantially higher temperature along the inner margin of the bight portion **3** and a substantially cooler temperature at the outer corners of the common connection of the legs **1, 2** and the bight **3**. In order to eliminate this condition, the heater A is formed with a pair of recesses **10** which extend toward the exterior wall of the bight **3**, in the manner as shown in FIGURE 1. The recesses **10** are somewhat circular and extend for the full vertical length of the bight **3**, that is, they extend from the top face thereof to the bottom face thereof. It has been found that by producing this type of recess, the current traveling through the legs **1, 2** is forced to move around the recess **10** and thereby create a higher temperature in a region which extends centrally along the bight **3**. Moreover, the area between each of the recesses **10** forms a heat sink for heat dissipation in the region of high current density. In this manner, it is possible to provide a more substantially uniform temperature distribution throughout the length of the bight **3**. Furthermore, this type of arrangement has eliminated the conditions of the prior art where the ends of the legs **1, 2** were substantially cold with respect to the inner margin thereof. In effect, the recesses **10** thereby form a heat sink **11** which is located between each of the legs **1, 2**.

It is possible to provide a modified form of graphite heater B substantially as shown in FIGURES 3 and 4, generally comprising a pair of horizontal legs **12, 13** which are connected by a bight portion **14**. The legs **12, 13** have top faces **15**, bottom faces **15'**, interior faces **16** and exterior faces **17**. Moreover, the legs **12, 13** are tapered from each of their transverse ends that is their free ends, which are adapted for ultimate attachment to a suitable furnace, such as an epitaxial silicon furnace. They are tapered in such a manner so that they have a slightly smaller cross sectional thickness at each of the ends than in the center portion thereof, when referring to the vertical dimension of the legs **12, 13** reference being made to FIGURE 5. Thus, it can be seen that the thickness of the legs increases as the distance from the free ends thereof increases. The angle of taper of each of the legs **12, 13** is so adjusted so that a cross sectional area of the legs **12, 13** is maintained in order to provide a substantially constant uniform temperature distribution across the lengths of the legs **12, 13**.

Each of the legs **12, 13** is connected by the bight **14** which is slightly thicker in the vertical dimension, reference being made to FIGURE 3, than each of the legs **12, 13**. For heaters having overall lengths of approximately 22 inches, the legs have an overall thickness of approximately 0.260 inch at the center portion and a thickness of approximately 0.215 inch at each of the ends. The bight **14** has an overall thickness of approximately 0.500 inch and has an overall length of approximately 1⅝ inches so that it is substantially thicker than the over-

all thickness of the legs **12, 13**. Moreover, by reference to FIGURE 4, it can be seen that the distance separating each of the legs **12, 13** has been substantially reduced so that it is only approximately ⅛ of an inch spacing. By reducing the spacing between each of the legs **12, 13**, it has been found that it is possible to eliminate much of the radiation from the internal walls of the legs **12, 13** and thereby maintain a more uniform temperature distribution across the length of each of the legs **12, 13**. The graphite heater B is also provided with a circular recess **19** at the point of connection with each of the two legs **12, 13**. The circular recess **19**, which has a diameter of approximately ½ inch, serves substantially the same purpose as each of the recesses **10** in the graphite heater A. In addition, the thickness of the bight **14** provides a larger current path so as to reduce the current density and thereby aids in maintaining uniform temperature across the bight **14**.

At each of the free ends of the legs **12, 13** that is the ends where they are normally attached to a clamp forming part of a furnace, the legs integrally merge into enlarged terminal portions **20, 21** respectively. The enlarged portions have a length of approximately 1 1/16 inches and have an overall thickness of approximately ¼ inch. Moreover, the terminal ends **20, 21** merge with the legs **12, 13** at an angle of taper of approximately 30°. It has been found that by selectively adjusting the angle of taper in order to adjust the thickness of the legs **12, 13**, it is possible to provide a substantially uniform temperature distribution across the entire length of the legs **12, 13**.

It should be understood that the present invention is not limited to heaters with only two legs and heaters with the particular shape and dimensions illustrated. For example, it is possible to provide heaters in accordance with the present invention which have three or more legs connected by a common bight portion. In this event, each of the legs of the heaters would be compensated in cross sectional area in order to maintain uniform temperature distribution across each of the legs.

In order to selectively alter the effective cross sectional area of the graphite heaters at selected portions of their length, the graphite heaters are normally mounted in a suitable epitaxial silicon furnace in the same manner as when used in a commercial operation. The free ends of the heaters are secured in clamps which may or may not be water cooled, depending upon the particular furnace. It is, of course, understood that the heater is normally cleaned for use in the same manner as it would be if it were to be used in a commercial operation.

Thereafter, it is necessary to measure the temperature produced at various selected portions along the length and width of the heaters. This can be accomplished by attaching thermocouples to the heater and connecting the leads thereof to a suitable temperaure readout device. However in actual practice, it has been found to be convenient to use an optical pyrometer. The graphite heater is then enclosed in a bell jar and current is passed through the heater in order to raise the temperature to a point within a range of normal operating temperatures. After the temperatures along selected portions of the length of the heater are recorded, the heater is cooled and the bell jar or so called "hat" is removed. At this point, the desired cross sectional area of the legs of the heater can be determined by simple electrical relationships. After the desired cross sectional area at selected portions along the length have been determined for the entire length thereof, the desired cross sectional area can be attained by removing the required amount of the cross sectional area. As pointed out above, this is accomplished by drilling small apertures. The apertures are sufficiently small so that they do not interfere with the internal strength of the heater, but yet, are sufficient in number so that they sufficiently alter the cross sectional area of the legs to accomplish the intended purpose.

In the case of the heater B, the variance in temperature for the new heater can be determined in the manner described above in connection with the heater A. Thereafter, it is possible to shave the upper and lower surfaces of the heater B in order to achieve the proper amount of taper so that a proper cross sectional area is maintained at selected portions along the length of the heater.

The invention is further illustrated by but not limited to the following examples:

EXAMPLE 1

This example illustrates the non-linear temperature distribution across the length of the heater when the heater is not compensated by alteration of cross sectional area at selected portions of its length for maintaining uniform temperature distribution. A graphite heater having an oveall length of approximately 24 inches and an overall width of approximately 3 9/16 inches was mounted in an epitaxial silicon furnace. Each of the arms had a width of approximately 1¼ inches in the transverse dimention. Moreover, each of the legs had an overall thickness of approximately ¼ inch and each of the legs was separated by approximately 1 1/16 inches. The bell jar temperature was maintained at approximately 730° C. throughout the entire experiment. The jar was maintained upder the pressure of 40 microns, and the power supplied to the heater was 28 volts at 470 amperes.

An optical pyrometer was used to measure the temperature of each leg at each of the twenty-three wafer positions on each leg. Hydrogen gas was then passed into the bell jar at a rate of 14 liters per minute at room temperature and the following temperatures of each of the wafer positions was measured and are recorded below.

Table I

Wafer Position No.	Distance From Attached Terminal (inches)	Temperature, ° C.
LEFT LEG		
1	2	947
2	3	1,080
3	4	1,123
4	5	1,143
5	6	1,149
6	7	1,153
7	8	1,157
8	9	1,167
9	10	1,175
10	11	1,178
11	12	1,176
12	13	1,178
13	14	1,180
14	15	1,185
15	16	1,178
16	17	1,180
17	18	1,177
18	19	1,175
19	20	1,179
20	21	1,168
21	22	1,158
22	23	1,108
23	24	1,042
RIGHT LEG		
46	2	941
45	3	1,072
44	4	1,120
43	5	1,139
42	6	1,147
41	7	1,157
40	8	1,164
39	9	1,174
38	10	1,176
37	11	1,184
36	12	1,188
35	13	1,187
34	14	1,188
33	15	1,187
32	16	1,184
31	17	1,183
30	18	1,179
29	19	1,187
28	20	1,176
27	21	1,173
26	22	1,158
25	23	1,105
24	24	1,040

The wafers nearest the free terminals of the heater are wafers **1** and **46**. The temperature of the bridge was plotted as a function of the bridge length as illustrated

in FIGURE 5 and it shows the non-uniform temperature distribution across each of the legs. Moreover, FIGURE 5 has two curves inasmuch as each of the legs of the graphite heater was not of the same temperature across its length.

EXAMPLE 2

This example also illustrates the non-linear temperature distribution across the length of the heater, similar to the heater in example 1 when the heater is not compensated by alteration of the cross sectional area at selected portions of its length. Hence, the heater in this example was also not capable of maintaining a relatively constant uniform temperature distribution across its entire length. The graphite heater used in this example has approximately the same dimentions as the graphite heater employed in Example 1. However, the bell jar temperature was maintained at 730° C. at the start of the experiment and at approximately 655° C. at the end of he experiment. The bell jar was maintained under a pressure of approximately 40 microns and this power supplied to the heater was 26 volts at 435 amperes.

An optical pyrometer was used to measure the temperature of twenty-two wafer positions on one leg of the heater and tweny-on wafer positions on the opposite leg of the heater. The bell jar was maintained under a vacuum of 40 microns and the following temperatures of each of the wafer positions were measured and are recorded below.

Table II

Wafer Position No.	Distance From Attached Terminal (inches)	Temperature, ° C.
LEFT LEG		
1	3	1,066
2	4	1,107
3	5	1,125
4	6	1,130
5	7	1,130
6	8	1,142
7	9	1,145
8	10	1,152
9	11	1,156
10	12	1,156
11	13	1,157
12	14	1,157
13	15	1,157
14	16	1,158
15	17	1,158
16	18	1,158
17	19	1,157
18	20	1,152
19	21	1,147
20	22	1,145
21	23	1,087
22	24	1,013
RIGHT LEG		
43	3	1,058
42	4	1,093
41	5	1,122
40	6	1,125
39	7	1,138
38	8	1,144
37	9	1,150
36	10	1,157
35	11	1,160
34	12	1,163
33	13	1,163
32	14	1,164
31	15	1,164
30	16	1,160
29	17	1,161
28	18	1,161
27	19	1,158
26	20	1,158
25	21	1,155
24	22	1,150
23	23	1,100

EXAMPLE 3

This example illustrates a temperature distribution across the legs of the graphite heater when the latter has been compensated for cross sectional area in order to maintain uniform temperature distribution. A graphite heater having an overall length of 24 inches was suitably mounted in an epitaxial silicon furnace and enclosed by a bell jar. The heater had an overall width of approximately 3 9/16 inches and each leg had an overall width in the transverse dimension of approximately 1¼ inches. The two legs had reliefs which were formed by slots having a thickness of ⅛ inch and extended inwardly from the interior surface of the bight portion for a distance of approximately ¼ inch. The slots terminated in slightly enlarged apertures having a radius of approximately ⅛ inch. Each of the legs is provided with 17 apertures extending for the entire width of the leg and having a diametral cross section of approximately 0.067 inch. The 17 apertures started at a point 3 inches from the free terminal margins of each of the legs and extended to a point 5 inches from the free terminal margins of the legs or for an overall distance of 2 inches. Accordingly, the 17 holes were spaced by distances of ⅛ inch. The legs were then provided with 8 apertures extending to a length of 7 inches from the free terminal margins and accordingly, each of the 8 apertures was separated by distances of ¼ inch from each other. Thereafter, each of the legs was provided with two apertures separated by ½ inch and two additional apertures separated by 1 inch thereby providing a total of 29 apertures which extended from a length 3 inches inwardly from the terminal margins of the legs to a point 10 inches inwardly from the free terminal margins of the legs.

The heater was maintained under a vacuum of 20 microns at room temperature at the outset and then hydrogen was passed into the "hat" at a rate of 15 liters per minute at atmospheric pressure. Current was supplied to the heater until the "hat" temperature was raised to 740 to 750° C. throughout the experiment. The power supplied to the heater was at 30 volts with 455 amperes.

An optical pyrometer was used to measure the temperature of 21 silicon wafer positions on each of the legs and the temperatures and the distances from the free terminal margins of the legs are recorded in the following table. (See Table III below.) The temperature of the bridge was measured and tabulated in Table III as a function of the bridge length for three different power settings. These data of temperature versus bridge for each of the power settings were plotted as shown in Figure 6. By reference thereto it can be seen that the three power settings were maintained at (a) 33 volts and 465 amperes, (b) 30 volts and 455 amperes, (c) 27 volts and 440 amperes. It can thus be seen, that for the greater portion of the length of each of the legs of the bridge, a substantially uniform temperature distribution had been maintained.

EXAMPLE 4

This example also illustrates the temperature distribution across the legs of a graphite heater when the latter has been compensated for cross sectional area in order to maintain uniform temperature distribution, in the same manner as the graphite heater of Example 3. The graphite heater employed in this particular example was substantially similar to the graphite heater employed in Example 3 and

Table III

Wafer Position No.	Distance From Attached Terminal (Inches)	Temperature, ° C. (a)	(b)	(c)
LEFT LEG				
1	3	1,118	1,103	1,082
2	4	1,183	1,175	1,148
3	5	1,192	1,184	1,158
4	6	1,190	1,184	1,153
5	7	1,188	1,180	1,153
6	8	1,185	1,175	1,150
7	9	1,185	1,175	1,150
8	10	1,185	1,175	1,150
9	11	1,185	1,175	1,150
10	12	1,185	1,175	1,150
11	13	1,185	1,175	1,150
32	14	1,185	1,375	1,350
13	15	1,385	1,175	1,150
14	16	1,385	1,175	1,150
15	17	1,185	1,175	1,150

Table III—Continued

LEFT LEG

Wafer Position No.	Distance From Attached Terminal (Inches)	Temperature, ° C. (a)	(b)	(c)
16	18	1,185	1,175	1,150
17	19	1,185	1,175	1,150
18	20	1,185	1,175	1,150
19	21	1,185	1,175	1,150
20	22	1,186	1,180	1,155
21	23	1,199	1,192	1,162
RIGHT LEG				
42	3	1,125	1,103	1,082
41	4	1,196	1,190	1,173
40	5	1,213	1,200	1,165
39	6	1,200	1,187	1,156
38	7	1,195	1,186	1,150
37	8	1,190	1,182	1,150
36	9	1,187	1,177	1,150
35	10	1,187	1,177	1,150
34	11	1,187	1,177	1,150
33	12	1,187	1,177	1,150
32	13	1,187	1,177	1,150
31	14	1,187	1,177	1,152
30	15	1,187	1,177	1,152
29	16	1,187	1,177	1,152
28	17	1,187	1,177	1,152
27	18	1,187	1,177	1,152
26	19	1,187	1,177	1,152
25	20	1,185	1,177	1,152
24	21	1,185	1,177	1,152
43	22	1,185	1,177	1,152
22	23	1,186	1,177	1,149

was similarly secured to an epitaxial silicon furnace and enclosed by a bell jar. The apertures formed in the side walls of the legs were substantially the same as those formed in the heater of Example 3.

The heater was maintained under a vacuum of approximately 20 microns at room temperature. The heater was the vacuum purged, purged at room temperature and then hydrogen was passed into the "hat" at a rate of 15 liters per minute. Current was supplied to the heater until the "hat" temperature was raised to approximately 740° C. to 750° C. throughout the experiment. The power supplied to the heater was 40 volts at 455 amperes. After approximately fifteen minutes the temperature of the wafers was measured and is recorded in the table set forth below as "Temperature No. 1." Shortly thereafter, trichlorosilane was passed into the "hat" at a rate of approximately 0.5 gram per minute.

A total of 19 silicon wafers was placed upon each of the legs and the distance from the free terminal margins of the legs are recorded in the table as set forth below. Recorded in the column designated as "Temperature No. 2" is the temperature of the bridge after the addition of the trichlorosilane.

Table IV

LEFT LEG

Wafer No.	Distance From Attached Terminal (inches)	Temperature No. 1, ° C.	Temperature No. 2, ° C.
1	4	1,158	1,152
2	5	1,172	1,165
3	6	1,172	1,165
4	7	1,166	1,165
5	8	1,166	1,165
6	9	1,174	1,165
7	10	1,174	1,165
8	11	1,174	1,165
9	12	1,174	1,165
10	13	1,174	1,166
11	14	1,169	1,166
12	15	1,176	1,166
13	16	1,174	1,158
14	17	1,170	1,156
15	18	1,174	1,150
16	19	1,168	1,150
17	20	1,163	1,148
18	21	1,163	1,148
19	22	1,164	1,148
RIGHT LEG			
38	4	1,157	1,146
37	5	1,170	1,155
36	6	1,171	1,157
35	7	1,171	1,157
34	8	1,171	1,159
33	9	1,175	1,163

Table IV—Continued

RIGHT LEG

Wafer No.	Distance From Attached Terminal (inches)	Temperature No. 1, ° C.	Temperature No. 2, ° C.
32	10	1,175	1,166
31	11	1,173	1,166
30	12	1,173	1,160
29	13	1,173	1,160
28	14	1,173	1,158
27	15	1,173	1,158
26	16	1,173	1,152
25	17	1,173	1,152
24	18	1,167	1,152
23	19	1,167	1,153
22	20	1,162	1,145
21	21	1,160	1,144
20	22	1,160	1,144

These temperature distributions could also be plotted as a function of the length of each of the legs to obtain curves similar to those plotted in FIGURE 7. It could thus be seen that a substantially uniform temperature distribution was maintained across each of the legs.

EXAMPLE 5

This example illustrates the temperature distribution across the legs of the graphite heater B which has been compensated for cross sectional area in order to maintain uniform temperature distribution. The graphite heater B had an overall length of 24 inches and an overall width of 5⅜ inches. Each leg had a width of approximately 2⅝ inches separated by a slot of ⅛ inch between each leg. Each of the legs of the graphite heater had an overall thickness in the vertical dimension of approximately ¼ inch. At its free end, the graphite heater terminated in an enlarged head portion having a length of 1$\frac{1}{16}$ inches and an overall thickness of .260 inch, at a point midway between their length. At the bridge end, each of the legs was integrally formed with enlarged head portions having a length of approximately 1⅝ inches and an overall thickness of .500 inch. Moreover, each of the legs at the point of attachment to the enlarged head portions had overall thicknesses of .230 inch. At points of attachment to the head portions at the free end, the legs had overall thicknesses of approximately 0.215 inch. At the head portion, the enlarged bridge was formed with an aperture having a diameter of approximately ½ inch, and is located at the point midway between each of the legs.

The heater was attached to an epitaxial silicon furnace having means for water cooling the heater at the point of attachment and was enclosed within a bell jar. The cooling water inlet temperature was maintained at 27° C. and the outlet water temperature was recorded to be 62° C. At the start of the operation, the pressure within the bell jar was reduced to 200 microns. The bell jar was then purged with gaseous hydrogen for approximately ten minutes. Gaseous hydrogen was thereafter passed into the bell jar at approximately 35 liters per minute (standard pressure and temperature). Current was then supplied to the heater until the temperature of the bell jar was raised to 780° C. The power supplied to the heater was 17.2 volts at 1070 amperes.

Shortly thereafter trichlorosilane gas was passed into the heater at a rate of 1.28 grams per minute. A doping gas, phosphorus trichloride, was added to the bell jar at a rate of approximately 25 milliliters per minute. A total of 35 wafers were placed on each leg of the heater and temperatures are recorded in the table set forth below (Table V). It is to be noted that there were two rows of wafers on each leg. The temperature of the heater was plotted as a function of the heater length as illustrated in FIGURES 7 and 8 and shows the relatively uniform temperature distribution across the length of the legs. The graph of FIGURE 7 shows the temperature of the wafer positions in each row on the left leg, and the graph of FIGURE 8 shows the temperature of the wafer positions in each row on the right leg.

Table V

LEFT LEG

Outer Row			Inner Row		
Wafer No.	Distance From Attached Terminal (Inches)	Temperature, ° C	Wafer No.	Distance From Attached Terminal (Inches)	Temperature, ° C.
1	4	1,153	36	4	1,150
2	5	1,154	35	5	1,151
3	6	1,155	34	6	1,155
4	7	1,154	33	7	1,158
5	8	1,155	32	8	1,156
6	9	1,156	31	9	1,157
7	10	1,157	30	10	1,158
8	11	1,156	29	11	1,158
9	12	1,155	28	12	1,157
10	13	1,156	27	13	1,156
11	15	1,155	26	14	1,157
12	14	1,155	25	16	1,157
13	15	1,156	24	17	1,157
14	16	1,155	23	18	1,158
15	17	1,154	22	19	1,157
16	18	1,152	21	20	1,156
17	19	1,151	20	21	1,155
18	20	1,150			
19	21	1,153			

RIGHT LEG

37	4	1,156	72	4	1,152
38	5	1,153	71	5	1,153
39	6	1,155	70	6	1,155
40	7	1,157	69	7	1,155
41	8	1,156	68	8	1,156
42	9	1,157	67	9	1,157
43	10	1,158	66	10	1,155
44	11	1,157	65	11	1,154
45	12	1,156	64	12	1,156
46	13	1,157	63	13	1,157
47	14	1,158	62	15	1,160
48	16	1,160	61	14	1,157
49	17	1,159	60	15	1,156
50	18	1,158	59	16	1,155
51	19	1,157	58	17	1,156
52	20	1,158	57	18	1,154
53	21	1,155	56	19	1,153
			55	20	1,150
			54	21	1,152

It should be understood that changes and modifications in the form, construction, arrangement and combination of parts presently described and pointed out may be made and substituted for those herein shown without departing from the nature and principle of my invention.

Having thus described my invention, what I desire to claim and secure by Letters Patent is:

1. An electrical heating element formed substantially of carbonaceous resistance material for use in epitaxial deposition furnaces and the like and being adapted to be heated by the passage of an electric current therethrough; said heating element comprising a plurality of longitudinally extending substantially coplanar legs, a bight portion extending across and operatively connecting one of the transverse ends of each of said legs, said legs having free opposed transverse ends adapted for operative attachment to a source of electrical power, each of said legs having a plurality of transversely extending selectively spaced apertures effective to reduce the cross sectional area of the legs, said apertures being sized to produce differences in the longitudinal cross sectional area and in resistance characteristics of said heating element to create a substantially uniform temperature across the length of each of said legs.

2. The electrical heating element of claim 1 further characterized in that a recess is formed in said bight portion adjacent each of said legs at the point of attachment to said bight portion to maintain uniformity of temperature in said bight portion.

3. The electrical heating element of claim 2 further characterized in that said recesses extend vertically.

4. The electrical heating element of claim 1 further characterized in that said heating element has only two legs.

5. The electrical heating element of claim 1 further characterized in that the spacing between each of said apertures is increased as the distance of the apertures from the transverse ends of the legs increases in the form of a geometric proportional increase.

References Cited

UNITED STATES PATENTS

1,318,028	10/1919	Thomson	338—217
2,596,327	5/1952	Cox et al.	338—217 X
2,569,773	10/1951	Orr	338—217 X
2,838,639	6/1958	Planer et al.	338—218 X
3,202,952	8/1965	Rayburn	338—195
423,223	3/1890	Dewey	338—215 X

FOREIGN PATENTS

345,138	12/1921	Germany.
35,103	10/1955	Germany.

RICHARD M. WOOD, *Primary Examiner.*

VOLODMYR Y. MAYEWSKY, *Examiner.*