

May 10, 1949.

R. S. OHL

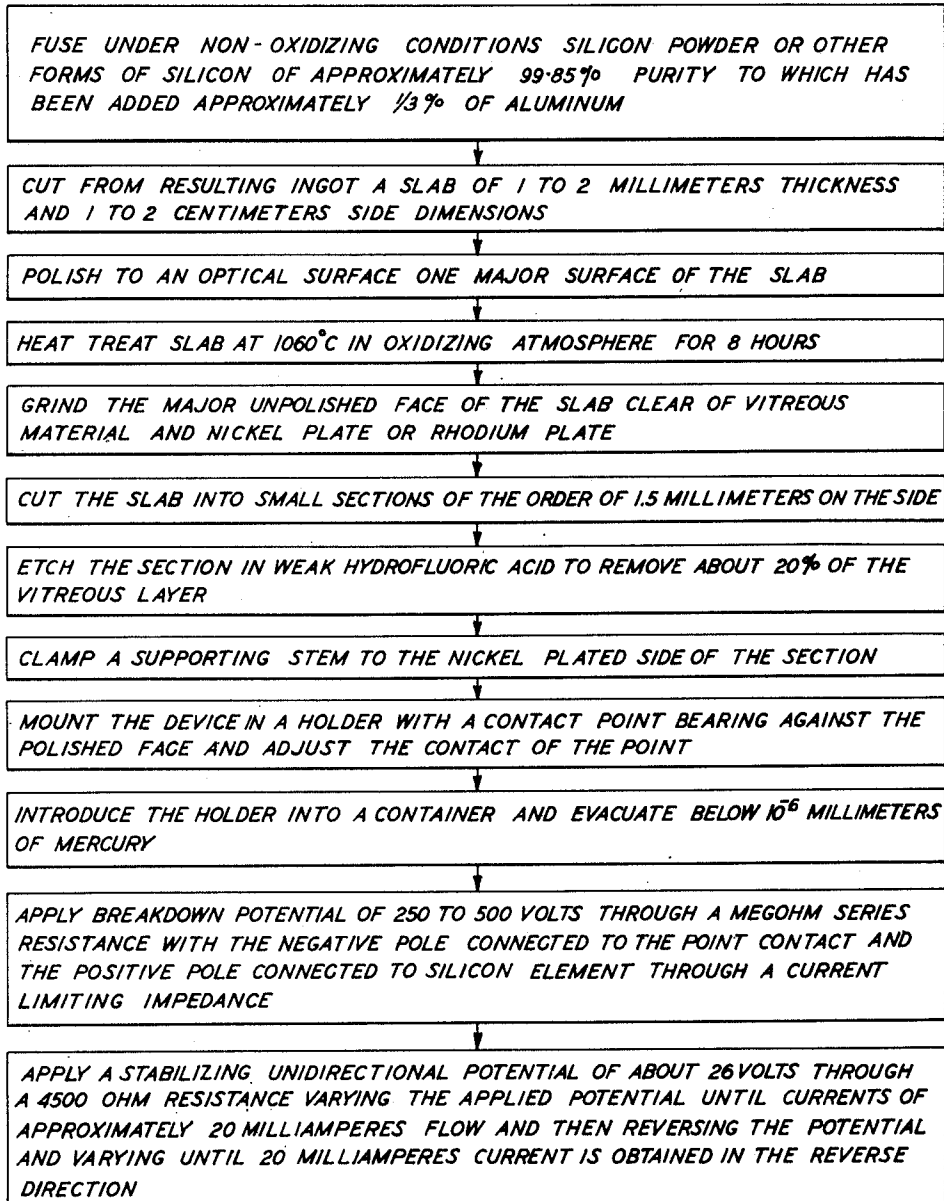
2,469,569

POINT CONTACT NEGATIVE RESISTANCE DEVICES

Filed March 2, 1945

4 Sheets-Sheet 1

FIG. 1.



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4 Sheets-Sheet 2

FIG. 2.

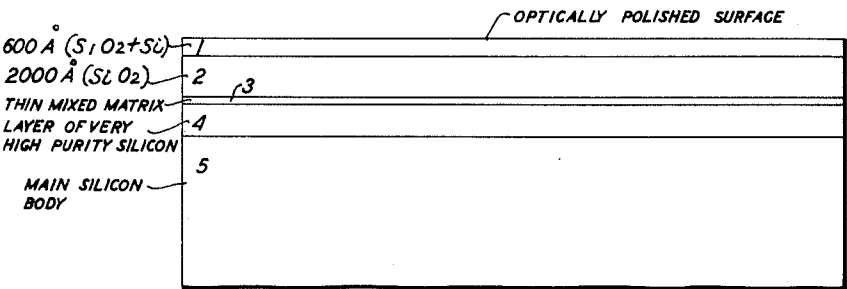


FIG. 3.

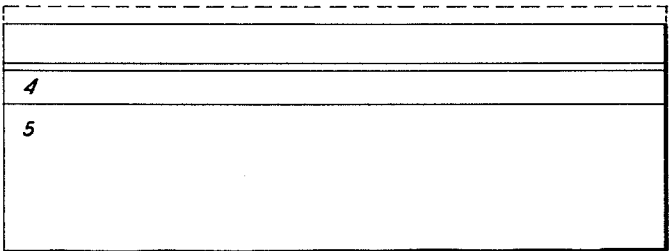


FIG. 4.

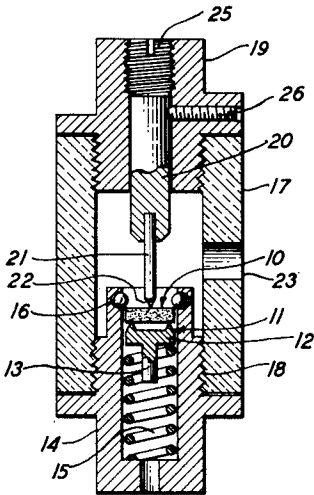
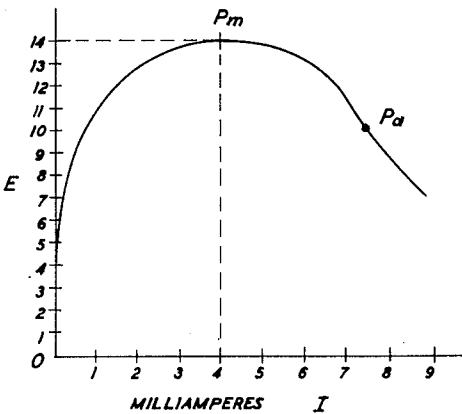


FIG. 7.



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POINT CONTACT NEGATIVE RESISTANCE DEVICES

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4 Sheets-Sheet 3

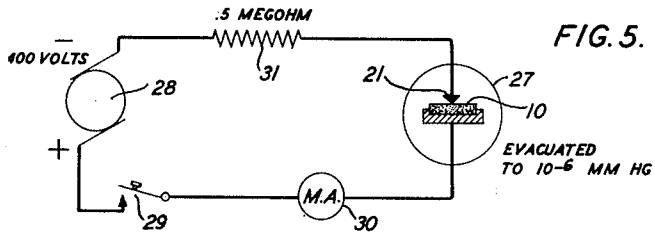


FIG. 5.

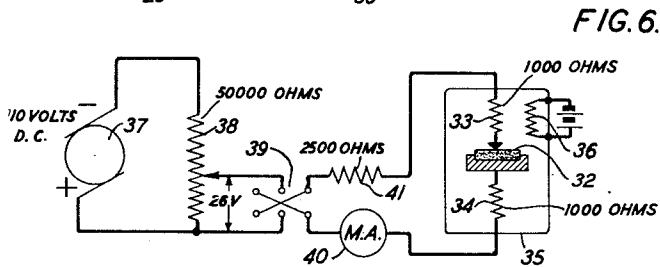


FIG. 6.

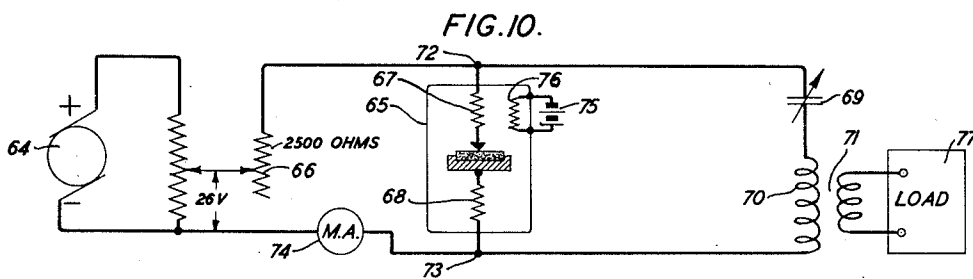


FIG. 10.

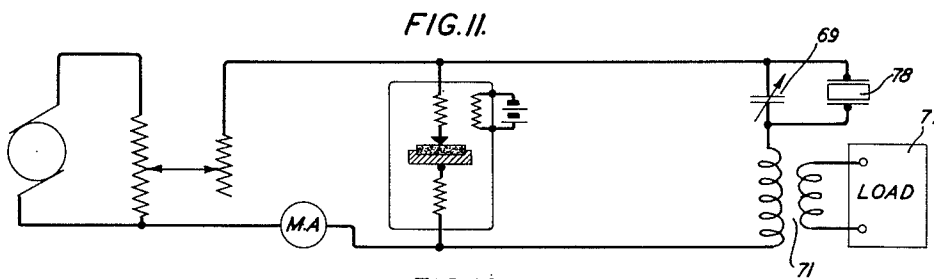


FIG. 11.

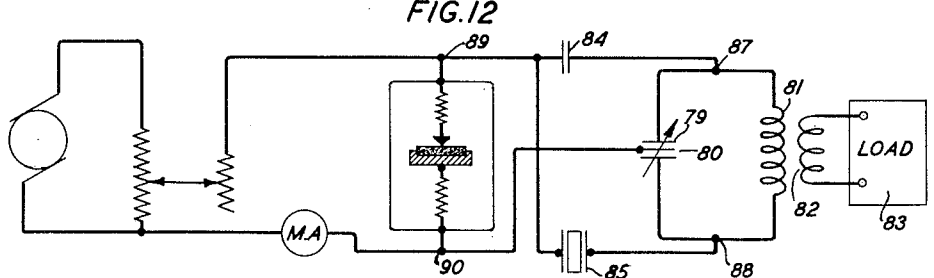


FIG. 12.

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4 Sheets-Sheet 4

FIG. 8.

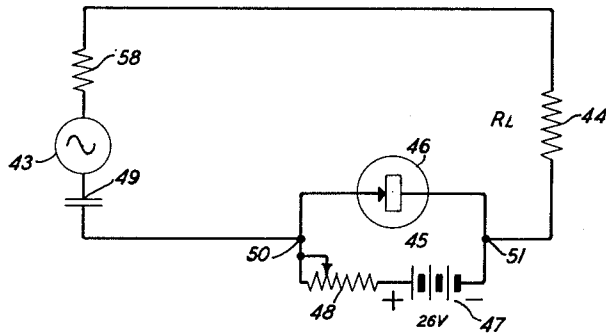


FIG.9.

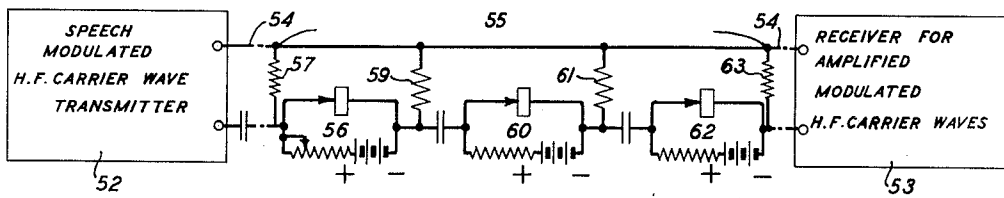
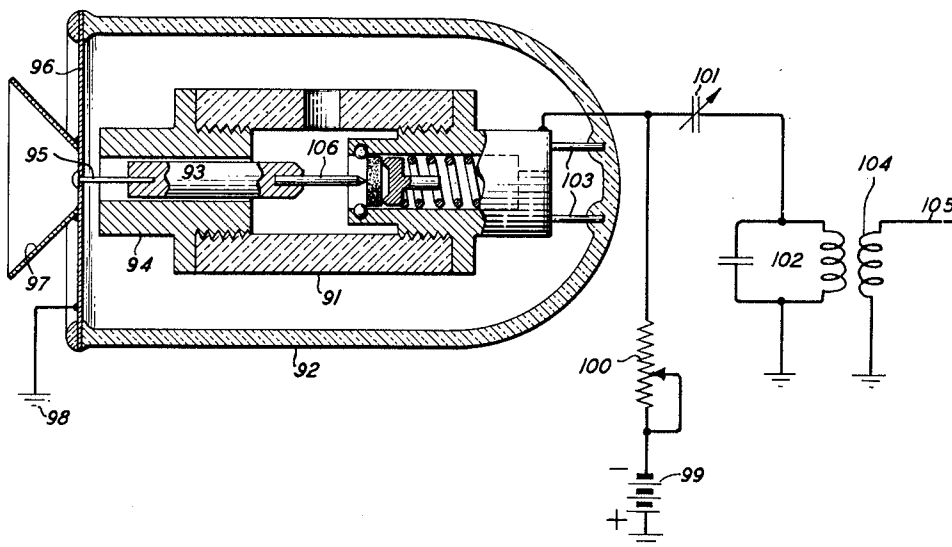


FIG. 13.



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2,469,569

POINT CONTACT NEGATIVE RESISTANCE DEVICES

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Application March 2, 1945, Serial No. 580,677

13 Claims. (Cl. 250—36)

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This invention relates to negative resistance elements utilizing point contact devices.

An object of the invention is to provide a point contact negative resistance device which shall be stable and efficient in its resistance characteristic.

A further object of the invention is to utilize a negative contact resistance device as a source of oscillations.

Another object of the invention is to provide a source of high frequency oscillations which does not require a space current tube.

An additional object of the invention is to provide a generator of oscillations which may be controlled by a piezo-electric frequency control without requiring a space discharge amplifier for maintaining the piezoelectric device in oscillation.

An additional aspect of the invention is a method of conditioning a silicon plate to enable it to present a negative resistance characteristic.

Silicon ingots may be produced by fusion of a high purity silicon powder which is commercially available with impurities of less than one-half per cent and ranging as low as fifteen-hundredths of one per cent. One suitable method of producing such high purity ingots is disclosed in the application of J. H. Scaff, Serial No. 386,835 filed April 4, 1941, issued as U. S. Patent 2,402,582, June 25, 1946, for Preparation of silicon materials. The fusion temperature of silicon is approximately 1410±10° centigrade. The high purity silicon powder may be fused in an electric furnace in which it is placed in a silica crucible which in turn is inside a graphite crucible. The electric furnace should be hermetically sealed so that it may be evacuated to minimize oxidization of the silicon. After exhaustion of the air the furnace may be filled with helium, nitrogen or hydrogen to protect the internal elements from oxidization and to reduce the evolution of gas which occurs upon solidification of the fused material. The fusion is effected by bringing the space within the silica crucible to a temperature of 1500° centigrade to 1600° centigrade. This may be accomplished by high frequency current traversing the windings of a coil adjacent the graphite crucible to induce high frequency current in the crucible. An analysis of high grade commercial silicon compared with the

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analyses of two different examples of the silicon material used in this invention shows:

	Commercial Silicon	Tucker Process Silicon	Electrometallurgical Company Silicon Lot 14743
	Percent	Percent	Percent
Silicon.....	98	99.95	99.85
Carbon.....	.01		.019
Iron.....	.69	.02	.031
Aluminum.....	.45	.02	.020
Calcium.....	.80	.009	.003
Manganese.....			.002
Phosphorus.....			.011
Magnesium.....	Nil		.007
Oxygen.....			.061
Hydrogen.....			.001
Nitrogen.....			.008
Insoluble.....	.06	.006	

Such an ingot consists in general of a zone of the material first cooled, an intermediate barrier zone and the zone of the material last cooled. The first zone has been termed the P zone since the direction of more easy flow of current between a plate of P zone material and a point contact is that corresponding to positive potential on the plate of the P zone material and negative potential on the point. Similarly the material of the third zone is termed N zone material since the more easy flow of current occurs when the potential of the contact point is made positive and that of the plate of silicon material is made negative.

It has been found that the zone characteristics in the ingots of the silicon material described are due to slight amounts of impurities. When the molten material solidifies from the top down it crystallizes as very high purity P type. However, as more high purity material is removed from solution the relative content of impurities in the remaining liquid increases. This forms the N type material constituting the lower portion of the ingot. The presence of certain metals, such as tantalum, will cause an otherwise highly pure silicon melt to produce an ingot having a zone of N material. The percentage of the whole ingot constituted by this N zone depends upon the relative quantity of the tantalum. Certain other impurities, such as boron and aluminum, predispose the silicon ingot to the opposite form, namely, that of P type material. It is therefore

possible by control of the purity of the material and in particular of the amounts of any P forming or N forming constituents which it may have to determine the proportions of the P zone and the N zone in the ingot as may be desired.

For the purposes of the present invention P type material is preferred. To insure securing a large proportion of P type material there is added to the otherwise high purity silicon before melting a small quantity of a P type producing material such as, e. g., $\frac{1}{2}$ per cent of aluminum or, in certain cases, small amounts of boron. With such treatment the barrier zone is present in the resulting ingot but is indeterminate and near the bottom of the melt. The lowermost portion of the ingot must generally be discarded in any event because of minute holes which develop during the solidification process. However, the major portion of the ingot yields satisfactory P type material.

There is one characteristic of the P type material which must be considered in design of apparatus. This material has an extremely high resistance which increases with the purity of silicon and tends to cause high energy loss at high frequencies. The aluminum appears to effectively reduce this resistance and the consequent energy loss without substantially affecting the surface characteristic of the final element which enables it to function as a negative contact resistance device.

In accordance with the present invention a slab is cut from an ingot of P type high purity silicon produced by fusion of such materials as the two for which analyses have been given and to which aluminum has been added to the order of $\frac{1}{2}$ per cent. One principal surface of the slab is optically polished and given a subsequent heat treatment for a period of eight hours or so at a temperature of the order of 1060° centigade, in an oxidizing atmosphere which causes the development of a glazed or vitreous surface. The major face of the slab which is opposite the polished face, is ground clear of the vitreous material and nickel plated or rhodium plated after which the slab is cut into small sections. In some cases it has been found desirable to evaporate platinum over the nickel plate to improve the contact characteristics of the nickel surface. Thereafter the sections are etched to remove a portion of the vitreous material from the polished face and to expose a surface of high purity silica. Each section so prepared and treated if provided with a fine metallic contact resting against its polished face and if suitably electrically conditioned will exhibit a negative resistance characteristic at the contact. Such a negative resistance device may be employed in conjunction with a polarizing unidirectional current generator as an amplifier or as a source of oscillations the frequency of which may be determined and controlled by suitable frequency control devices well known in the art of electrical oscillation production.

In order to make clear what is meant in this specification by negative resistance it may be noted that for steady unidirectional current passing through an element the resistance of the element is measured by the ratio of the E. M. F. E expended thereon to the current I passing therethrough. Since in an unvarying unidirectional current system current can proceed through an ordinary resistor in response to an electromotive force only in the direction which corresponds to an electron stream passing from the negative pole of the source through the resistor and back

to the positive terminal of the source the resistance or ratio of E to I is always positive. In the signaling art in almost all cases we are concerned with the effects produced when an applied electromotive force is changed by an amount δE and since these effects are increments ΔI in current of the ratio of the increment electromotive force to the increment current or the "incremental resistance" is of prime interest.

$$R_{inc} = \frac{\Delta E}{\Delta I}$$

remains positive as long as the current and the impressed E. M. F. both increase, i. e., change by positive increments. At a certain point the current begins to rise relatively rapidly and the potential difference across the device falls. In the region beyond that critical point positive increments of current take place with negative increments of E. M. F. meaning that the incremental resistance is negative. As long as operation is confined to currents in that region increasing current is attended with falling E. M. F. and decreasing current with increasing E. M. F. It is such incremental resistances with which this invention is concerned. However, in lieu of the more accurate expression "negative incremental resistance" the simpler designation "negative resistance" will be employed in the specification and claims.

In the drawing:

Fig. 1 shows schematically the process of producing a device having a negative resistance characteristic in accordance with the invention;

Fig. 2 shows a portion of a section of a silicon slab at the termination of the sixth step of the process of Fig. 1;

Fig. 3 shows the silicon section of Fig. 2 after the conclusion of the etching process of the seventh step;

Fig. 4 shows the silicon section of Fig. 3 clamped and mounted in a holder at the conclusion of step 9 of the process of Fig. 1;

Fig. 5 is a schematic diagram of the circuit used in the eleventh step of the process of Fig. 1 for breaking down the high resistance of the heat treated and etched high purity silicon;

Fig. 6 is a schematic of a stabilizing circuit used in the final step of the process of Fig. 1;

Fig. 7 is a graph of the voltage current characteristic of a device constructed in accordance with the process of Fig. 1;

Fig. 8 is a schematic diagram of an amplifying circuit utilizing the negative resistance device;

Fig. 9 shows a carrier wave telephone transmission system with an intermediate repeater comprising a three-stage amplifier in accordance with the invention;

Fig. 10 is a schematic of a circuit for producing oscillations utilizing the negative resistance device of the invention;

Figs. 11 and 12 present modifications of the schematic circuit of Fig. 8; and

Fig. 13 is a circuit schematic of a combined carrier wave oscillator and speech modulator utilizing a negative resistance device.

The process of producing a negative resistance device in accordance with this invention is outlined in the skeleton schematic of Fig. 1. As has previously been explained, there is added to silicon powder or other forms of silicon material of a purity of the order of 99.85 per cent, aluminum amounting to approximately $\frac{1}{2}$ per cent of the whole. In some instances other substances,

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such as boron, which tend to form P type material may be added. The silicon is fused under non-oxidizing conditions as described in the application Serial No. 386,835 issued as U. S. Patent 2,402,582, June 25, 1946, of J. H. Scaff to produce an ingot. From the P zone portion of the ingot a slab of 1 to 2 millimeters thickness and 1 to 2 centimeters side dimensions is cut and polished to an optical surface on one major face as disclosed in the application of R. S. Ohl, Serial No. 530,419 filed April 10, 1944, issued as U. S. Patent No. 2,437,269, March 9, 1948, for Translating device and method of making it. The slab is then heat treated in an oxidizing atmosphere at 1060° centigrade for a period of approximately eight hours.

The resulting slab will have a glassy or vitreous surface. The slab is then ground on the major unpolished face to entirely remove the vitreous material and the face thus ground is plated with nickel or rhodium. Thereafter the slab is cut into small sections of the order of 1.5 millimeters on a side.

Fig. 2 indicates in an approximate manner the cross-section structure of a small silicon section with the optically polished surface at the top. The vitreous material comprises three layers designated 1, 2 and 3 the upper layer of which may be of the order of 600 Å. of a mixture of silica and silicon. The second layer as indicated may be of the order of 2000 Å. in thickness and is of substantially pure silica. Below the silica layer is a very thin sheet 3 comprising a mixed matrix which in effect cements the vitreous material to the unvitified material beneath. Below the layer 3 is a fourth layer of very high purity silicon. Finally is the main silicon body 5 which is very much thicker than any of the other layers and consists of a relatively high purity silicon but with a slight impurity content. It should be understood, of course, that the thickness of the vitreous surface and consequently of the various layers will vary with the length of the oxidizing heat treatment.

The next step in the process of Fig. 1 is to etch the sections in weak hydrofluoric acid to remove that portion of the vitreous material constituting layer 1 of Fig. 2. At room temperature about 1 Å. of vitreous layer may be removed per second for each percent of hydrofluoric acid. In about 50 seconds a 12 per cent acid will remove the top or outer layer of 600 Å. thickness thus exposing the intermediate or silica layer 2 of Fig. 2. Since the outer layer 1 will vary in thickness in accordance with the period and conditions of the oxidizing heat treatment a rough general rule to follow is that the etching should be continued for a period sufficient to remove 20 per cent to 30 per cent of the thickness of the vitreous portion.

It may be noted that the etching in accordance with the present invention is carried less far than in the disclosure of Ohl Patent No. 2,437,269, supra, in which the polished surface was etched to remove layers 1, 2 and 3 and to expose the layer 4 of very high purity silicon.

Following the etching the silicon section is in condition for assembly in a rectifying unit as indicated in Fig. 4. The silicon section 10 is clamped in position with its lower nickel plated face in contact with the upper margin of a circular rib 11 projecting upwardly from the upper surface of a circular head 12 fitting closely within the central longitudinal bore of a terminal member 14 and provided with a stem 13. In assembling the apparatus a spiral spring 15 is first in-

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troduced within the bore and the stem 13 is then introduced with its head 12 bearing against the spring. The rib 11 serves to provide an adequate electrical contact with the nickel plated lower surface of the silicon section 10 while at the same time greatly reducing heat transfer by conduction from section 10 to the head 12. This causes section 10 to operate at a higher temperature and facilitates the initiation and maintenance of the negative resistance reaction. Next the silicon element 10 is introduced and it is retained in place against the action of the spring 15 by a resilient retaining ring 16 which snaps into an annular recess in the wall of the circular bore. The terminal member 14 is then screwed into one end of the ceramic cartridge 17 which is threaded to receive it as indicated at 18. The cartridge 17 is provided at its opposite end with a somewhat similar terminal plug member 19 through the longitudinal bore of which is introduced a closely fitting cylindrical holding member 20 in the lower recessed tip of which is seated a wire contactor 21 the pointed tip 22 of which bears against the polished face of silicon element 10. The contactor 21 preferably consists of a tungsten wire 0.02 inch in diameter and its tip is ground to produce a conical or pencil point the sides of the cone extending at an angle of about 30 degrees with the central axis of the wire. The contactor 21 may be held in place within the socket in holder 20 by soldering or in any other desired manner. The cartridge is provided with an opening at 23 to enable inspection and adjustment of the position of the tip of contactor 21 with reference to the silicon surface. There may be used if desired in lieu of the ceramic cartridge 17 a transparent plastic cylinder. Holder 20 is positioned by an adjusting screw 25 which is aligned coaxially with the holder. When the desired adjustment is attained the holder 20 may be locked in position by a set screw 26 extending through a boss on the side of the terminal plug 19. The pressure of contact point 22 upon the silicon plate 10 should be very light. In apparatus which has been found satisfactory this pressure may be of the order of 3 grams. The negative resistance device of Fig. 4 may now be introduced into an air-tight container which is thereafter evacuated to a pressure below 10⁻⁶ millimeters of mercury.

After the mechanical assemblage of the negative resistance unit has been completed it is necessary to give it an electrical conditioning to reduce the surface resistance and impart a negative resistance characteristic. This may be effected as indicated in Fig. 5 by introducing the negative resistance unit 27 into a circuit including in series a source 28 of unidirectional current, a switch 29, a milliammeter 30 and a high resistance resistor 31. The source 28, although indicated as of 400 volts, may have an E. M. F. ranging from 250 to 500 volts. The resistor 31 may range from 0.5 megohm to a megohm. The source 28 is connected with its negative terminal toward contactor 21 and its positive terminal toward the silicon plate 10. When the switch 29 is closed the milliammeter 30 indicates a very minute current which suddenly increases as the resistance of the silica layer 2 breaks down but which is limited by the resistor 31 to avoid injury which might otherwise occur to the fine tip 22 of contactor 21. The protective resistor 31 should be placed electrically very near to the contact device so that there may be no burning at the tip 22 in consequence of releasing of a capacity charge at the breakdown. The effect of the application of this breakdown

potential appears to be to draw electrons from the contactor 21 and to puncture the silica layer 2 with perhaps submicroscopic holes in many places.

After the initial breakdown has occurred, it is found helpful to stabilize the device by use of the circuit of Fig. 6. The negative resistance device 32 is illustrated as a somewhat different modification with series resistors 33 and 34 each of the order of 1000 ohms within the exhausted container 35. Although not ordinarily employed there may be included, if desired, a heater unit 36 having leads passing through the exhausted container and to which may be connected a heating source. A potential of approximately 26 volts is applied from the unidirectional source 37 through a potentiometer 38, a reversing switch 39, a milliammeter 40, and a series resistor 41. After closure of the switch 39 the potentiometer 38 is varied until the current passing through the device 32 attains a magnitude of about 20 milliamperes as indicated by meter 40. Switch 39 is then reversed to cause current to pass in the opposite direction through the device 32 and the applied potential is again adjusted until a current of approximately 20 milliamperes has been obtained. This operation requires only a few minutes and serves to stabilize the contact. The negative resistance element is now ready for use. In operation it is employed with a polarizing source the positive terminal of which is connected to the point contactor and the negative terminal to the silicon plate since with this polarization it is much more stable and much less noisy. However it will operate with the opposite polarization.

The resistance characteristic of a negative resistance unit constructed and stabilized in accordance with this invention and as has been described is illustrated by the graph of Fig. 7. As the applied E. M. F. increases from zero the device behaves initially as a very high resistance but after the E. M. F. has reached 5 or 6 volts the current begins to increase more rapidly than does the E. M. F. so that the ratio of total applied E. M. F. to resulting current I falls. However, as long as an increase in the applied E. M. F. yields an increase in the output current the "incremental resistance" remains positive. A definite transition in the nature of the characteristic is reached at a point P_m somewhere in the neighborhood of 4 milliamperes for the specimen whose graph is illustrated in Fig. 7. After reaching that point the current I continues to rise even though the over-all potential E is permitted to decrease. It is in this range beyond the point P_m in which an increase in the potential difference between the terminals results in a reduction in current or a decrease in the terminal potential difference results in an increase in current, that the device exhibits negative resistance. Of course, the operation of such a device should be stabilized by adequate series resistance to prevent overload and destruction of the contact tip if that form of characteristic extends over a range of current of sufficiently high magnitude to cause such destruction.

Fig. 8 illustrates the application of a negative resistance device constructed in accordance with the invention in an amplifier circuit. The alternating current source 43 which may typify any source of signaling current or other variable current is shown connected to a load resistor 44 through an amplifier 45. The amplifier 45 comprises a negative resistance element 46 of the type which has been described. It is polarized by a

source 47 of 26 volts E. M. F. through a resistor 48. A series capacitor 49 is shown to preclude application of other unidirectional E. M. F. to the device 46. In operation the amplifier 45 and its polarizing loop including source 47 and resistor 48 are adjusted to some such point on the characteristic of Fig. 7 as that indicated by P_m at which an increase in the current through the device 46 corresponds to a decrease in the potential difference between the points 50 and 51. It follows that any tendency of the source 43 to increase the current flowing through the circuit of that source including in series the load resistor 44 and the amplifier 45 will occasion not only the proportional variation in current through the load resistor 44 which might be expected, but a more than proportional variation; for example, if the current in the series circuit increases, the potential difference between terminals 50 and 51 of the amplifier device 46 will fall. Consequently the potential difference across load resistor 44 will correspond not only to that normally to be expected but in addition to the increment occasioned by the drop in potential between points 50 and 51. Accordingly, variations in E. M. F. originating in the source 43 will give rise to still greater variations in the potential difference across load resistor 44 with a corresponding change in the series current through the load resistor.

Fig. 9 shows a high frequency carrier wave telephone system in which the terminal apparatus 52 serves to originate speech modulated high frequency carrier waves to be transmitted to a remote receiver 53 adapted to receive and detect the speech modulated carrier waves and to produce audio frequency speech currents corresponding to those by which the carrier wave was modulated at the transmitter. The apparatus 52 at the transmitting station is connected to the apparatus 53 at the receiving station over a transmission line 54 including an intermediate three-stage repeater 55. The first stage 56 of the repeater may be substantially identical with the amplifier of Fig. 8 it being understood that the shunt input resistor 57 serves as a source of varying input E. M. F. in lieu of the variable source 43 of Fig. 8 with its internal resistance 58. The shunt output resistor 59 of the amplifier 56 corresponds to the load resistor 44 of Fig. 8. In similar manner the shunt resistor 59 may serve as the source of input E. M. F. for the second amplifier stage 60 the output shunt resistor 61 of which serves in turn as the source of input E. M. F. for the amplifier stage 62. It transpires that weak currents incoming over the line 54 at the three-stage repeater 55 will traverse the shunt resistor 57 to set up a resulting potential difference thereacross which will be greatly magnified by the three-stage amplifier and impressed across the output resistor 63 for retransmission over the outgoing section of line 54 to the receiving apparatus 53.

Fig. 10 discloses one form of circuit which has been found suitable for use with the negative resistance device of this invention for production of oscillations. In this circuit the source 64 of unidirectional potential which may be a battery of primary cells, a dynamotor, an electric generator or an alternating current amplifier applies a potential of approximately 26 volts to the negative resistance device 65 through a variable external resistor 66 of about 2500 ohms and through its internal resistors 67 and 68 each of approximately 1000 ohms. A tuned oscillation circuit compris-

ing a variable condenser 69 and an inductor 70 which also serves as the primary winding of the transformer 71 is connected between the external terminals 72 and 73 of the negative resistance device. Oscillations readily take place with about three milliamperes of current flowing through the device as indicated by meter 74. For oscillation conditions and the layer thicknesses of the silicon section described the potential difference existing at the terminals 72 and 73 of the device 65 is about 12 volts and about 36 milliwatts are dissipated in the device.

Although the device has been disclosed as incorporated in a highly evacuated container after once having been activated it may thereafter operate even at atmospheric pressure but with low stability. It is therefore advisable if the device is not to be operated under the conditions of high vacuum illustrated in Fig. 10, to stabilize the conditions at the contact by application of a sealing and protective coating of wax while the device is under high vacuum. This tends to preclude changes of physical position and of chemical conditions in the region of point contact.

Although it is not essential and is not ordinarily used it may in some circumstances be found helpful to facilitate the operation of the device by raising its temperature. This may be accomplished by supplying heating current from source 75 to the heater 76.

A load 77 may be connected to the secondary winding of transformer 71 to withdraw therefrom useful oscillations of the frequency of the tuned circuit 69, 70. A relatively wide frequency range of oscillations is obtainable with a circuit of this character ranging from frequencies of a few thousand cycles up to frequencies of several megacycles.

Fig. 11 shows a modification of the circuit of Fig. 10 in which the frequency determining circuit includes a quartz or other piezoelectric or mechanical vibrational resonator 78 connected in parallel with the variable condenser 69. The resonator 78 serves to determine and to stabilize the frequency of the oscillations supplied by the oscillator through its output transformer 71 to the load 77.

Fig. 12 discloses another modification of the circuit of Fig. 10 in which the tuned circuit 69, 78 and 71 is replaced by a balanced frequency selective system. This system consists of a variable condenser 79 having a movable armature 80 positioned intermediate two fixed capacitor plates. The condenser 79 is connected in a tuned loop circuit with an inductor 81 which may constitute the primary of a transformer 82 supplying oscillations to the load 83. One common terminal 87 of the condenser 79 and the inductor 81 leads through a fixed capacitor 84 to the terminal 89 of the negative resistance device. The other common terminal 88 of the condenser and inductor is connected to the same terminal 89 of the negative resistance device through a piezoelectric element 85 which may be of the well-known quartz or tourmaline type. Terminal 90 of the negative resistance device is connected to the movable armature 80 of the condenser 79. The tuned loop circuit 79, 81 is preferably tuned to the predetermined frequency of the oscillations which it is desired to supply to the load 83. Piezoelectric element 85 is likewise designed to have a natural resonance frequency corresponding with the frequency of the desired oscillations. Capacitor 84 is designed to have a capacitance substantially equal to the static capacitance of piezoelectric

element 85. It transpires therefore that alternating potential differences existing between the terminals 89 and 90 and of such frequency as to be remote from a resonance frequency of the piezoelectric element 85 will cause equal and opposed electromotive forces to be impressed respectively between the armature 80 and the terminals 87 and 88 of the tuned circuit. However, at the resonance frequency of the piezoelectric element 85 the balance of these electromotive forces no longer exists and the tuned circuit will be vigorously excited to cause oscillations of its natural frequency to be sustained. In this manner the circuit of Fig. 12 serves to supply to the load 83 oscillations of controllable and of very highly stable frequency.

Fig. 13 discloses an apparatus employing a negative resistance device in accordance with the invention to serve both for production and modulation of carrier wave oscillations. The negative resistance device per se is shown at 91 and corresponds in its details to the device of Fig. 4. It is supported within the container 92 by small metal rods 103 attached at one end to a terminal plug of the negative resistance device and embedded at the other end in the dielectric envelope 92. At the remote end the device 91 is provided with a contactor holder 93 which is slidable in its surrounding plug 94 and connected by a metallic driving rod 95 with a diaphragm 96 which serves as a closure for the container 92. Fixed on the diaphragm is a mouthpiece 97. The diaphragm is electrically connected to ground as at 98. It will be apparent that the negative resistance device is connected in an oscillator circuit. A polarizing source 99 with its positive terminal grounded is connected through the variable resistor 100 to the silicon element of the negative resistance device. In shunt to the negative resistance device is a path including a variable condenser 101 and a closed loop frequency determining circuit 102 which is inductively coupled to the secondary winding 104 connected in the output circuit 105. It will be apparent that the negative resistance device of Fig. 13 will serve to produce in the tuned circuit 102 and to supply to the output circuit 105 oscillations of the frequency of the circuit 102. It will also be apparent that sound waves directed toward the mouthpiece 97 and impinging upon the diaphragm 96 will vary the pressure exerted on the silicon plate by the tip of the contactor 106, thus producing variations in the resistance of the contact and consequently producing variations in the amplitude of the oscillations generated.

What is claimed is:

1. A source of oscillations comprising a body of P-type highly pure silicon having two substantially parallel faces, a metallic layer of high conductivity intimately joined to one of said faces, a layer of vitreous material including silicon and silicon dioxide intimately joined to the other of said faces, a pointed fine metallic contactor in pressure contact with said layer of vitreous material, said vitreous material having submicroscopic holes in the portion intermediate said contactor and said body, a source of polarizing electromotive force connected between said metallic layer and said pointed contactor causing the path between said metallic layer and said pointed contactor which path includes said vitreous material and said P-type silicon to exhibit a negative characteristic of resistance with respect to a changing applied electromotive force, a loop tuned circuit including an inductor and a three-termi-

nal capacitor for determining the frequency of the oscillations, an electrical connection from said metallic layer to the central terminal of said capacitor, and electrical paths connecting said pointed contactor with each terminal of said inductor, said last-mentioned paths including respectively a piezoelectric element and a capacitor having a static capacitance equal to that of the piezoelectric element, and a load circuit electrically coupled to said inductor.

2. An oscillation source comprising a body of P-type highly pure silicon having two substantially parallel faces, a metallic layer of high conductivity intimately joined to one of said faces, a layer of vitreous material including silicon and silicon dioxide intimately joined to the other of said faces, a pointed fine metallic contactor in pressure contact with said layer of vitreous material, said vitreous material having submicroscopic holes in the portion intermediate said contactor and said body, a source of polarizing electromotive force connected between said metallic layer and said pointed contactor causing the path between said metallic layer and said pointed contactor which path includes said vitreous material and said P-type silicon to exhibit a negative characteristic of resistance with respect to a changing applied electromotive force, and an output circuit having a frequency-determining means connected to said metallic layer and said pointed contactor.

3. An oscillation source comprising a body of highly pure silicon having two substantially parallel faces, a metallic layer of high conductivity intimately joined to one of said faces, a layer of vitreous material including silicon and silicon dioxide intimately joined to the other of said faces, a pointed fine metallic contactor in pressure contact with said layer of vitreous material, a first resistor having one of its terminals connected to said metallic layer, a second resistor having one of its terminals connected to said pointed contactor, an evacuated container within which said resistors and the said elements connected therebetween are insulatingly mounted with external leads connected to the free terminals of said resistors respectively, an energizing path including a source of polarizing electromotive force in series with a current-limiting element connected to said external leads causing the electrical path within said container between said leads to exhibit a negative characteristic of resistance with respect to a changing applied electromotive force, a resonant circuit including a capacitor and an inductor in series connected between said external leads outside of said container, and an output circuit also coupled to said external leads.

4. The method of producing a negative resistance element which comprises cutting a flat slab from an ingot of high purity silicon, heating said slab in the presence of air to a temperature of about 1060° centigrade for a period of several hours, subjecting one face of said slab to an acid etchant to remove the outer layer of the glaze thereon, and subjecting the surface from which the outer layer has been removed to a conditioning electromotive force of the order of 400 volts to break down the resistance of the surface layer uncovered by the etching process.

5. An oscillation generator comprising a silicon body having a surface contacted by a metallic contactor over a small area the electrical path between and including said body and said contactor exhibiting a negative resistance characteristic with respect to changing applied electromotive

forces, terminals connected respectively to said body and to said metallic contactor, an energizing circuit including a source of electromotive force and an impedance element in series therewith connected to said terminals, and an alternating current load circuit including frequency-determining elements also connected to said terminals, said surface of said silicon body being formed by heating in the presence of air to a temperature of about 1060° centigrade for a period of several hours a flat slab from an ingot of highly pure silicon, subjecting one face of said slab to an acid etchant to remove the outer layer of glaze thereon, and subjecting said face from which the outer layer of glaze has been removed to a conditioning electromotive force of the order of 400 volts with the negative polarity applied to the terminal connected to said metallic contactor and the positive polarity applied to the terminal connected to said body to break down the resistance of the surface layer uncovered by the etching process.

6. The method of producing a negative resistance element which comprises subjecting a plate of highly pure silicon to a temperature of the order of 1000° centigrade under oxidizing conditions for a period of several hours and removing the resulting outer layer from one of the surfaces of the plate to a depth of the order of 600 Angstrom units to produce a device exhibiting at said surface a resistance which varies in an inverse manner to that of the electromotive force applied between the reduced face and a point contact bearing thereon.

7. The method of producing a negative resistance element which comprises subjecting a plate of highly pure silicon to a temperature of the order of 1000° centigrade under oxidizing conditions for a period of several hours to produce a glazed surface layer and removing the resulting outer layer from one of the surfaces of the plate to a depth of the order of 20 per cent of the thickness of the glazed surface layer to produce a device exhibiting at said surface a resistance which varies in an inverse manner to that of the electromotive force applied between the reduced face and another face.

8. An oscillator comprising a body of silicon of purity in excess of 99 per cent heat treated for several hours at a temperature in excess of 1000° centigrade to produce a vitreous layer of silicon and silicon dioxide on at least a portion of the surface of said body, said treated body having some of the outer portion of said vitreous layer removed by etching to a depth sufficient to expose a layer of substantially pure silicon oxide and another portion of the surface of said body consisting of silicon of the original purity of said body, a pair of terminals connected respectively to the exposed surface of said silicon oxide and said other portion of the surface of said body, an output circuit including frequency-determining elements connected between said terminals, and means for connecting a source of polarizing electromotive force to said terminals with its negative pole to the terminal on the silicon oxide and its positive pole to the said other terminal causing the path between said terminals which includes silicon oxide to exhibit a negative characteristic of resistance with respect to a changing applied electromotive force.

9. A negative resistance device comprising a body of highly pure silicon, a layer of vitreous material intimately joined to a surface of said body which layer includes a thin matrix in contact with

said surface of said body, a layer of substantially pure silicon dioxide overlying said thin matrix, and a top layer of a mixture of silicon and silicon dioxide overlying said layer of substantially pure silicon dioxide, a pointed contactor engaging the exposed surface of said layer of vitreous material, input and output terminals connected to said contactor and a portion of said body remote from said layer of vitreous material, and means for polarizing the body negatively with reference to said contactor causing the electrical path between said contactor and said body through said vitreous material to exhibit a negative characteristic of resistance with respect to a changing applied electromotive force.

10. An electrical translating device comprising a body of high purity silicon constructed to exhibit a negative resistance characteristic when in contact with a fine wire point, a pointed contactor of tungsten engaging with pressure a surface of said body, said surface being formed by heating in an atmosphere containing oxygen to a temperature in excess of 1000° centigrade for a period of several hours a flat slab from an ingot of high purity P-type silicon to produce a glazed surface layer, subjecting one face of said slab to an acid etchant to remove approximately 20 per cent of the glaze thereon resulting from said heating, and subjecting said face from which some of the glaze has been removed to a conditioning electromotive force of the order of 400 volts with the negative polarity applied to said contactor and the positive polarity applied to the silicon of said body at a position removed from said contacted surface to break down the resistance of the contacted surface layer, terminals connected respectively to said contactor and said body, a loop tuned circuit including an inductor and a three-terminal capacitor for determining the frequency of oscillation, an electrical connection from one of said terminals to the central terminal of said capacitor and electrical paths connecting said other terminal with each terminal of said inductor, said last-mentioned paths including respectively a piezoelectric element and a capacitor having a static capacitance equal to that of the piezoelectric element, and means for applying a steady polarizing electromotive force to said first-mentioned terminals causing the electrical path through said glaze to exhibit a negative characteristic of resistance with respect to a changing applied electromotive force.

11. An oscillation source comprising a negative resistance element of the silicon contact rectifier type, a loop tuned circuit including an inductance and a three-terminal capacitor for determining the frequency of the oscillations, an electrical connection from one terminal of the negative resistance element to the central terminal of the capacitor and electrical paths connecting the other terminal of the negative resistance element with each terminal of the inductor, said last-mentioned

paths including respectively a piezoelectric element and a capacitor having a static capacitance equal to that of the piezoelectric element.

12. A negative resistance device comprising a body of P-type highly pure silicon having separated surface portions, a metallic layer of high conductivity intimately joined to one of said surface portions, a layer of vitreous material including silicon and silicon dioxide intimately joined to another of said surface portions, and a pointed fine metallic contactor in pressure contact with said vitreous material, said vitreous material having submicroscopic holes in the portion intermediate said contactor and said body.

13. A negative resistance device comprising a body of P-type highly pure silicon having substantially parallel faces, a metallic layer of high conductivity intimately joined to one of said faces, a layer of vitreous material including silicon and silicon dioxide intimately joined to the other of said faces, a pointed fine metallic contactor of tungsten in pressure contact with said vitreous material, said vitreous material having submicroscopic holes in the portion intermediate said contactor and said body, a first resistor having one terminal connected to said metallic layer, a second resistor having one terminal connected to said contactor of tungsten, and an evacuated container having said resistors, metallic layer, layer of vitreous material, body of silicon, and pointed metallic contactor insulatingly supported within said container with leads from the free terminals of said resistors respectively passing through and insulated from each other by the walls of said container.

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