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ELECTRICAL COUPLING DEVICE

Filed Dec. 12, 1968

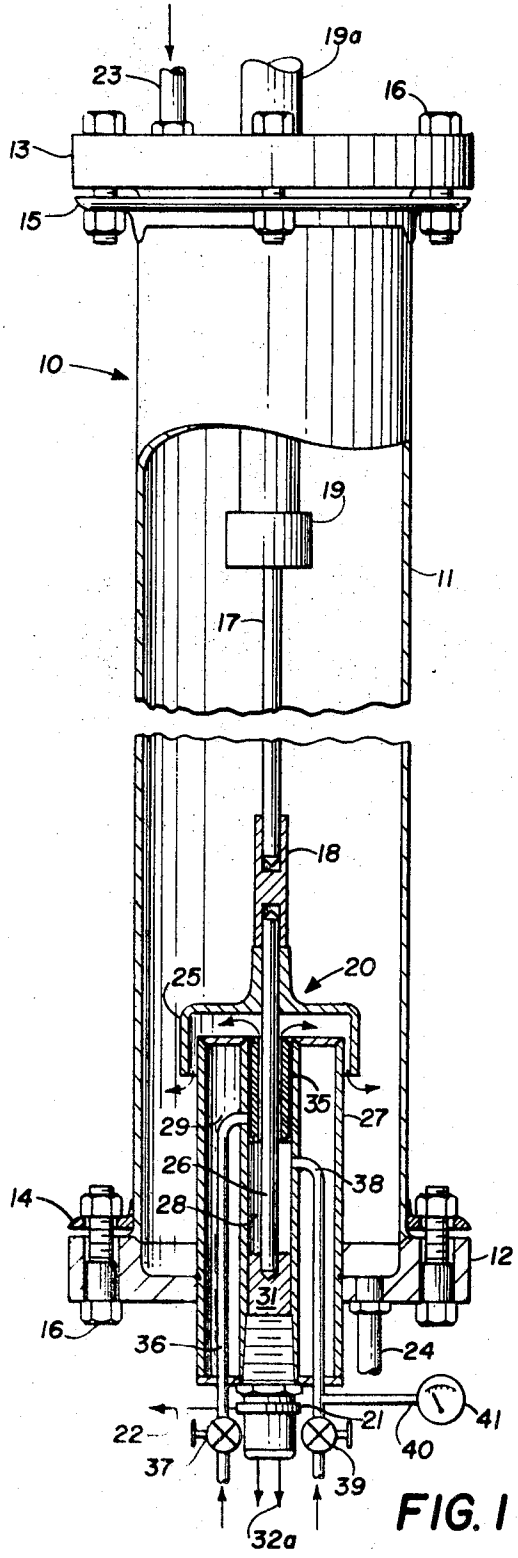


FIG. 1

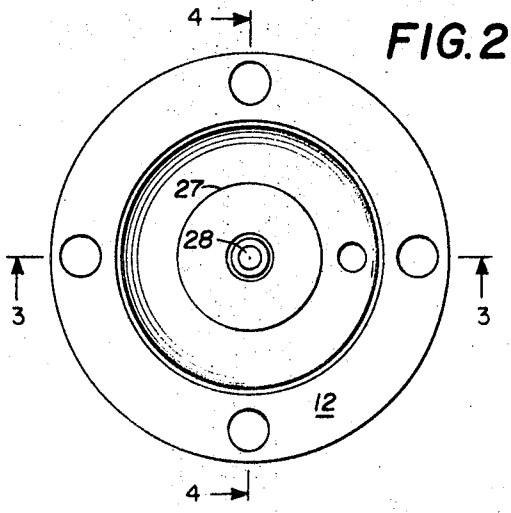


FIG. 2

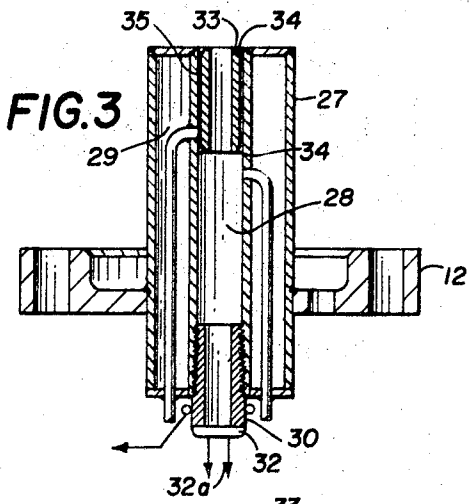


FIG. 3

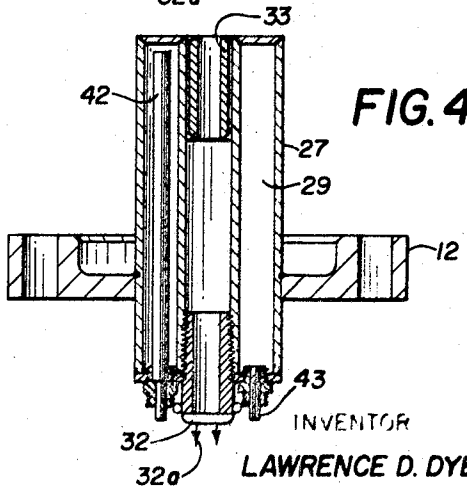


FIG. 4

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ELECTRICAL COUPLING DEVICE

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ABSTRACT OF THE DISCLOSURE

An electrical coupling device which is particularly adapted to maintain contact between an electrical lead and an electrical resistance filament and allow movable but substantially frictionless contact during the expansion and contraction of the filament wherein the electrical lead floats in an electrically conductive molten or liquid metal body. A gas shield means is operatively associated with said lead.

This invention relates to electrical coupling devices. In another aspect, this invention relates to a device for electrically coupling and controlling the stress on a resistance filament such as a filament of semiconductor material during operations involving the vapor phase deposition of semiconductor material upon the filament.

Semiconductor materials such as silicon and germanium are commonly used in the manufacture of semiconducting devices such as diodes, transistors, and integrated circuits. A conventional method for producing the semiconductor material suitable for the manufacture of electronic components involves the vapor phase deposition of the semiconductor material on a heated filament made from the same material. According to these methods an elongated generally cylindrically or flat sided filament is placed within a reactor such as a quartz tube which is fitted with suitable end plates and graphite electrodes within which the ends of the starting filament are clamped. The filament is then heated by developing a potential across the graphite electrodes and thereby passing current therethrough.

During most operations the filament is initially heated to an elevated temperature of about 1300° C., for example, and treated with vapors such as hydrogen or a hydrogen halide to pre-condition the surface of the filament by etching. Next, the temperature of the filament is lowered to a temperature of about 1250° C. and a gaseous stream of hydrogen and a silicon halide is passed over the filament. The gaseous components in the stream will react upon contacting the hot starting element and thereby deposit silicon on the surface of the element. Conventional procedures of this type are disclosed in U.S. 3,168,422 and U.S. 3,172,791.

When practicing the above-described process in conventional equipment, problems have arisen which result in non-uniform growth and/or defects in the grown semiconductor material due to (1) stresses which arise from sideward restraint and non-axial positioning of the upper and lower chucks, and (2) stresses which occur due to longitudinal expansion of the filament as it is heated from ambient temperature to the etching and deposition temperature. The stress caused by this longitudinal expansion can lead to bowing of the formed semiconductor rod and to irregularly deposited semiconductor rods. This in turn results in expensive handling problems during technological processing of the semiconductor rod. Additionally, if the filament is monocrystalline and it is desired to deposit semiconductor material in single crystal

form, then the expansion can cause a stress increase that generates an undesirable dislocation content in the crystal which many times yields the product unsuited for electronic purposes.

Conventional methods of alleviating the stress induced by longitudinal expansion of the filament during the deposition process generally allow for slippage between the semiconductor filament and the electrode chuck. However, when applying these conventional techniques, unwanted frictional forces still result which can cause the undesirable stress condition in the filament. Additionally, when applying these conventional techniques, welding between the filament and the graphite chuck sometimes occurs during the heat up, which will yield the undesirable stress condition during both the heat-up operation as the filament expands and the cooling-down operation as the filament contracts.

Therefore, one object of this invention is to provide a novel electrical coupling device.

Another object of this invention is to provide a means for electrically coupling a resistance filament with an electric lead while controlling the stress on the resistance filament during expansion and contraction thereof.

A further object of this invention is to provide a device for coupling an electrical lead with a resistance filament to thereby allow movable but substantially frictionless contact between the filament and the lead during heating and cooling of the filament as it expands and contracts.

Still a further object of this invention is to provide a means for preventing irregularly formed crystal rods and crystal defects within crystal rods of semiconductor material caused by stresses induced in the rod as it expands and contracts between electrical leads during a vapor phase deposition process for producing semiconductor rods.

According to the invention a coupling device is provided for coupling a pair of electric leads which is particularly adapted to electrically couple a resistance filament and an electric lead and allow movable but substantially frictionless contact between the filament and the lead during expansion and contraction of the filament.

According to anotner embodiment of this invention an electrical coupling device is provided for maintaining constant and substantially frictionless contact between an electrical lead and a semiconductor filament which is positioned vertically between an upper electrode and the coupling device in a vapor phase deposition reactor for producing semiconductor rods, and wherein the coupling device is provided with means to support a portion of the weight of the filament during heating and cooling thereof to prevent plastic deformation of the filament. The electrical coupling device of this invention generally comprises a conductive rod which is operatively connected to the semiconductor filament and which cooperates in a substantially frictionless manner with a pool of conductive liquid. The device is further porvided with a gaseous barrier for preventing vapors from the conductive liquid pool from communicating with the interior of the deposition reactor.

This invention can be understood more easily from a study of the drawings in which:

FIG. 1 is an elevation view partly in section showing a preferred embodiment of this invention attached to a reactor for producing a crystalline semiconductor rod by vapor phase deposition;

FIG. 2 is a plan view of the bottom end plate for the reactor of FIG. 1;

FIG. 3 is a sectional view taken along lines 3—3 of FIG. 2; and

FIG. 4 is a sectional view taken along lines 4—4 of FIG. 2.

Now referring to FIG. 1 reactor **10** comprises a cylindrical quartz reactor tube **11** which is held between end plates **12** and **13** by ring clamps **14** and **15**, respectively. End plates **12** and **13** are secured to ring clamps **14** and **15** by nut and bolt assemblies **16**. Semiconductor filament **17** is positioned within reactor **10** and held in electrical communication between graphite chucks **18** and **19**. Electrode **19***a* extends through end plate **13** and connects to graphite chuck **19**. Electrical coupling device **20** connects between graphite chuck **18** and electrode clamp **21** carrying lead **22**. Electrode **19***a* and lead **22** connect to a conventional electric power source.

Conduit **23** extends through end plate **13** and serves to introduce reactant gases to the interior of reactor **10**. Conduit **24** extends through end plate **12** and functions to remove by-product gases and unreacted reactants from the interior of reactor **10**.

Electrical coupling device **20** comprises a bottom section and a top section which is movable in a vertical relationship to the bottom section. The top section of electrical coupling device **20** comprises gas shield **25**, chuck **18**, and rod **26** which extends downwardly from the inner face of gas shield **25** into socket chamber **28** of the bottom section of coupling device **20**.

The bottom section of coupling device **20** is carried by end plate **12** as shown in FIGS. 1–4. The bottom section of electrical coupling device **20** generally comprises a tubular housing **27** which encloses cooling chamber **29**, and a socket chamber **28** which is adapted to receive rod **26** as illustrated in FIG. 1.

Referring to FIGS. 1 and 3, the bottom of socket chamber **28** is closed by plug **30**. As illustrated in FIG. 3, plug **30** is generally a hollow cylindrical plug which is closed at its lower end and threaded at its upper end and thereby adapted to threadably engage screw threads positioned in the lower end of socket chamber **28**. Plug **30** functions to retain a conductive fluid **31** such as a molten or liquid metal. Heating device **32** is attached to the bottom of plug **30** for the purpose of supplying sufficient heat to maintain metal **31** in the liquid state. Leads **32***a* are connected to a conventional power source. Electrode clamp **21** is positioned around plug **30** as described above.

Porous bushing **33** which is a generally gas permeable cylindrical member is positioned adjacent the open end of socket chamber **28**. Bushing **33** can be any tubular porous metal known in the art such as a porous bronze pre-lubricated bushing which has been heated to remove the oil therefrom. Porous bushing **33** is suspended in the open end of socket **28** by holding members **34** which engage and seat with indentations around either end of bushing **33** to yield an annular space **35** between the wall of socket chamber **28** and the outside periphery of porous bushing **33**.

Control gas inlet conduit **36** extends through housing **27**, cooling chamber **29** and the upper portion of socket chamber **28** to communicate with annular space **35**. Control valve **37** is operatively positioned within control gas inlet conduit **36**. Control gas outlet conduit **38** communicates between the interior of socket chamber **28** below porous bushing **33** and pressure control valve **39**. Conduit **40** is positioned within conduit **38** at a point upstream of control valve **39**, and is operatively connected to pressure gauge **41**.

Now referring to FIG. 4 which is a sectional view along lines 4—4 of FIG. 2, the cooling system for the bottom section of electrical coupling device **20** is illustrated. Coolant inlet conduit **42** extends through housing **27** to a point adjacent the upper end of housing **27** wtihin cooling chamber **29**. Coolant outlet conduit **43** communicates through the bottom of housing **27** to the lower portion of cooling chamber **29**.

The basic cylindrical reactor illustrated in FIG. 1 can be used for the vapor phase deposition of semiconductor materials known in the art such as for example silicon, germanium and compounds of Groups III–A and V–A of the Periodic Table as illustrated on page B2 of the Handbook of Chemistry and Physics, Chemical Rubber Co., 1964. However, for purposes of illustration this invention will be described in relation to the production of a silicon rod. In operation, a seed filament of silicon **17** is initially retained between chucks **18** and **19**. In most conventional operations the reaction chamber is initially evacuated by a vacuum source and current is then passed through filament **17** until filament **17** is heated to an elevated temperature of about 1325° C. Next, etching vapors such as for example, hydrogen and hydrogen chloride, are passed into the reactor through inlet conduit **23** and exhausted therefrom via outlet conduit **24** in a predetermined manner for a predetermined time, for example, 30 minutes. The use of electrical coupling device **20** during this initial heat up will prevent unwanted warping of the filament **17** and perturbed crystal areas therewithin by allowing filament **17** to expand longitudinally against substantially no opposing frictional forces.

Therefore, when operating according to this invention current is initially supplied through leads **32***a* to heating device **32** to cause metal **31** to melt. Any highly conductive fluid which will not decompose or flash at the temperature within socket chamber **28** can be used in the practice of this invention such as for example, mercury, however, it is preferred that the fluid be a metal that solidifies above room temperature in order that the interior of the reaction chamber can be evacuated before heating of the filament **17** without pulling contaminating amounts of metal vapors inside the chamber. Gallium is the most preferred liquid conductor because it has a low vapor pressure, melts at about 30° C. and super cools before solidification. Therefore, this invention will be described with reference to gallium as conductive fluid **31**. When heating device **32** has melted gallium **31** and rod **26** is free to move within the pool of liquid metal, valves **37** and **39** are opened to allow control gas to flow from porous bushing **33** and out both from under gas shield **25** and conduit **38**. The control gas can be any gas which is nondeleterious to the etching procedure and noncontaminating to the subsequent deposition procedure. Preferably, the control gas is hydrogen. The action of hydrogen flowing through porous bushing **33** will cause a gaseous pressure gradient to exist adjacent the opening of socket chamber **28**. Thus, the pressure at the center of porous bushing **33** will be greater than the pressure at either end of porous bushing **33**. This pressure gradient will in effect provide a gaseous barrier and prevent vapors from the liquid gallium **31** from entering the interior of the reaction chamber. Any vapors emitted from liquid gallium **31** will be removed with the hydrogen flowing through control gas outlet conduit **38**. Additionally, the action of the hydrogen flowing through porous bushing **33** will cause substantially uniform gas pressure around rod **26** and thereby align rod **26** in the opening of socket chamber **28** so that any vertical movement of rod **26** relative to socket chamber **28** will be substantially frictionless.

At this point pressure valve **39** is slowly closed. This action will cause increased pressure on liquid gallium **31** which in turn will force rod **26** upward. Valve **39** is adjusted until the pressure read by gauge **41** will be sufficient to support the weight of the upper section of electrical coupling device **20** comprising rod **26**, gas shield **25**, and chuck **18**, and one half the weight of filament **17** while providing a sufficient flow to hold rod **26** in a spaced relationship from the inside surface of porous bushing **33**. This offsetting pressure will allow filament **17** to expand uniformly during heating without unnecessary distortive forces acting thereon.

Next, cooling water is allowed to flow in conduit **42**, circulate through cooling chamber **29** and flow out conduit

43. Cooling chamber 29 is not necessary in all electrical coupling operations, but is preferred to prevent undesirable expansion of housing 27 which can cause contact with gas shield 25. Likewise, the presence of gas shield 25 and the particular shape of gas shield 25, comprising a plate extending radially from rod 26 and ending in a downwardly directed baffle, are not necessary for all electrical coupling operations. However, gas shield 25 having the configuration illustrated in FIG. 1 is preferred in this particular embodiment to (1) deflect reactant gases and by-products of the deposition process from socket chamber 28 and (2) direct hydrogen gas flow from socket chamber 28 to outlet conduit 24. At this time, the action of the hydrogen gas flowing through porous bushing 33 results in a substantially frictionless contact of rod 26 within socket chamber 28, controls the vertical tension on filament 17, and serves as a barrier to prevent metal vapors from entering the interior of reactor tube 11.

Next, electrical current is passed through filament 17 in a conventional manner and etching vapors are passed through reactor 10 as previously described. At the end of the etching step the current through filament 17 is normally reduced to yield a temperature of about 1250° C. and conventional gaseous reactants such as for example, trichlorosilane, hydrogen chloride and hydrogen are passed through the reaction chamber in contact with filament 17. After the initial heating procedure, the flow of hydrogen gas through electrical coupling 20 can be reduced by partially closing valve 37. This action will stop the gas bearing action of electrical coupling device 20 while maintaining the gas barrier and maintaining the pressure within conduit 38 at a value to offset the weight of the top section of electrical coupling device 20 and approximately one half of the weight of filament 17. Thus, since filament 17 has already expanded, it is not necessary that frictionless electrical contact be made with lead 22 at this time.

Just prior to the end of the deposition procedure when current through filament 17 is stopped, valve 37 is opened further to produce again the gas bearing action of electrical coupling device 20. Pressure within exit conduit 38 is maintained at a value which will offset the weight of the top section of electrical coupling device 20 and approximately one half of the weight of the grown silicon rod. Current flow through filament 17 is then shut off and filament 17 is allowed to cool and contract with substantially no distortive forces acting thereon.

Any suitable construction material can be used in coupling device 20. It is generally preferred that chuck 18 be made of graphite or any other conventional, electrically conductive chuck material. Rod 26 should be made of a material which will not dissolve or react with conductive fluid 31, or allow conductive fluid 31 to diffuse through its lattice, for example, stainless steel. Additionally, gas shield 25 should be made of a generally noncorrosive material such as stainless steel.

While this invention has been described in relation to its preferred embodiments, many modifications which fall in the scope of this invention will not be apparent to those skilled in the art upon reading this disclosure. The coupling device of this invention can be used in most operations where it is necessary to maintain constant but substantially frictionless contact between two electric leads. Additionally, in some low temperature operations, the basic coupling device of this invention will function effectively without cooling chamber 29 and/or gas shield 25.

I claim:

1. An apparatus for maintaining constant and substantially frictionless contact between first and second electric leads comprising:

(a) A tubular socket means having an open end and closed end in axial communication and adapted to hold a pool of conductive liquid when positioned with the open end upward;

(b) Means to operatively connect said first lead with said pool of conductive liquid;

(c) An elongated contact rod, adapted to be suspended over said socket means and have one end operatively connected to said second lead and the other end extend into said socket means and contact said pool of conductive liquid;

(d) Friction control means for passing a substantially uniform flow of gas from around the inside periphery of said socket means and thereby hold said contact rod in spaced relationships therefrom as it contacts said pool of conductive liquid.

2. An apparatus for maintaining constant and substantially frictionless contact between the lower end of a vertically positioned electric resistance filament and an electric lead as the filament expands and contracts comprising in combination:

(a) A tubular socket member having an open upper end and a closed lower end and carrying a pool of conductive liquid therein;

(b) Means for connecting said electrical lead to said pool of conductive liquid;

(c) Porous gas distribution bushing means positioned around the interior of said open end of said socket member;

(d) Means to supply gas flow to said porous bushing means;

(e) Exhaust conduit means to remove gas from said socket member below said porous bushing means;

(f) An elongated conductive rod means having one end adapted to connect to lower end of said filament and the other end extending through said open upper end of said socket member into said pool of conductive liquid.

3. The apparatus of claim 2 further comprising the means for controlling pressure within said exhaust conduit means.

4. The apparatus of claim 2 further comprising a gas shield means extending radially from said conductive rod above the open end of said socket means.

5. The apparatus of claim 4 wherein said gas shield means carries a tubular shaped baffle on the outside periphery thereof which extends in spaced relationship around said tubular socket member.

6. The apparatus of claim 5 further comprising a heat exchange means positioned around said tubular socket member, for cooling said tubular socket member.

7. The apparatus of claim 2 wherein said conductive liquid is a liquid metal.

8. The apparatus of claim 2 further comprising heating means to maintain said conductive liquid in the liquid state.

9. The apparatus of claim 8 wherein said conductive liquid is a metal.

10. The apparatus of claim 9 wherein said metal is gallium.

11. A coupling device for maintaining constant and substantially frictionless contact between the lower end of a vertically positioned semiconductor filament and an electric lead as the semiconductor filament expands and contracts in a vapor phase deposition reactor for growing semiconductor materials comprising in combination:

(a) A tubular socket member having an open upper end and a closed lower end and carrying a pool of conductive liquid therein;

(b) Means for connecting said electrical lead to said pool of conductive liquid;

(c) Means for providing a gaseous pressure gradient above said pool of conductive liquid in said socket member to prevent vapors from said pool from entering the interior of said reactor; and

(d) An elongated conductive rod means having one end adapted to connect to lower end of said filament and the other end extending through said open

upper end of said socket member into said pool of conductive liquid.

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MORRIS KAPLAN, Primary Examiner

U.S. Cl. X.R.

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