METHOD OF PRODUCING BORON-GOLD ALLOY FOIL

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Our invention relates to a method for producing a p-doped region in bodies consisting of essentially monocrystalline semiconductor material, preferably silicon, by alloying onto the semiconductor body a foil of boron-containing gold.

This invention is based upon our discovery that the boron-containing gold required for such purposes is advantageously produced by first intimately mixing gold powder and boron powder, then compacting the mixture under pressure, thereafter tempering the pressed body at a temperature below the melting temperature of gold, subsequently melting the pressed and sintered body, and thereafter rolling the remelted material down to foil thickness. This discovery was made in the face of prior views that boron cannot be melted together with gold because it tends to become expelled from the melt, as explained below.

It is known to produce an n-doped region in bodies of silicon by alloying a donor element, for example antimony, into the gold component prior to joining that component with the silicon. It is further known to produce a p-doped region in bodies of semiconductor material by alloying onto the bodies a part consisting of aluminum. This method has the disadvantage of requiring relatively high temperatures (700° C.) whereby the lifetime of the minority charge carriers is more strongly reduced than when alloying gold components into the semiconductor body, the latter method being applicable at a lower alloying temperature (400 to 500° C.).

Many attempts have been made toward making the favored conditions afforded by the alloying of doping-containing gold also applicable for the purpose of producing p-doped regions. It has been tried, especially, to thus introduce boron into the semiconductor material, because boron would permit the obtaining of a high doping concentration, due to the high solubility of boron in silicon, the distribution coefficient being near unity. However, the introduction of boron by diffusion, by a known method, possesses the disadvantage of demanding extremely high temperatures (900 to 1300° C.), thus entailing a great reduction in life-time of the minority carriers. Since boron could not be melted together with gold because it does not dissolve in gold but tends to become expelled from the melt, it has been proposed that solid boron be introduced into the liquid gold-silicon alloy. This can be done, for example, by first mechanically rolling amorphous boron in powder form into a gold foil or by spreading the solid boron in fine distribution upon the foil, whereafter the gold foil is placed upon the semiconductor body and the assembly is subsequently heated. Then the gold forms a liquid alloy with a portion of the semiconductor material, in which alloy the boron penetrates down to the alloying front.

It is an object of our invention to bond a boron-containing gold foil with a semiconductor body by alloying rather than diffusion. More particularly it is an object of the invention to produce boron-containing gold, to prepare foils from such boron-containing gold, and to produce a p-doped region in semiconductor bodies by an alloying method.

We have discovered that by means of the method according to our invention boron becomes dissolvable in gold after all. When gold powder and boron powder are intimately mixed, then kept compacted under pressure and are tempered several days at a temperature below the melting temperature of gold, a sufficient quantity of boron diffuses into the intimately adjacent gold or vice versa, so that in this manner a mixture akin to a boron-gold alloy results. It has been found that in such processing, the boron is no longer present within the gold in relatively coarse pieces but mainly in molecular distribution. Even during subsequent melting and rolling of the material down to foil thickness, no de-mixing takes place to any appreciable extent.

Consequently, it then becomes feasible to melt the tempered, pressed body together with a further quantity of gold and/or other materials, particularly such other materials that improve the quality of the alloy. For example it has been found preferable to add slight quantities of gallium and/or indium to the gold foil, in amounts of from 0.1 to 1%, preferably 0.3 to 0.4%.

These two substances, likewise acting as to be acceptors (p-doping), increase the doping concentration here only to a negligible extent, but they greatly facilitate wetting, and the alloy formation, thus affording a considerably improved reliability with respect to the control of the alloying method.

It has further been found favorable to admix in or incorporate with the boron-containing gold foil an additional trace content of oxygen and/or sulfur, for example, preferably in the order of magnitude of a few milli-percent. The quantity of oxygen may be 0.001 to 0.02%, the quantity of sulfur may preferably be 0.001 to 0.01%.

This also affords improving the quality of the alloy. Furthermore, slight additional quantities of bismuth, for example 0.1% to 1% and particularly 0.3 to 0.4% relatively to the weight of the gold, may be employed. The bismuth addition promotes the occurrence of a planar alloying front. The slight n-doping action cannot produce a detrimental effect due to the strong p-doping action of the boron.

The boron content of the foil may be 0.001 to 0.3%, being preferably about 0.1%, in respect to the gold, all percentages herein being by weight.

A preferred embodiment of the method is as follows.

Gold powder and boron powder are intimately mixed with each other and are then subjected to pressure. The mixture of gold powder and boron powder may contain 0.01 to 0.5% boron. An advantageous embodiment of the invention contained 0.35% boron in the powder mixture.

The finished foil then contains about 0.3% boron, because slight quantities of boron precipitate at the external surfaces. It has been found preferable to apply the highest feasible pressure, for example in the order of 10,000 atm. The preferred range of the pressures to be employed is from 10 to 100,000 atmospheres, with a pressure of at least 2000 atmospheres desirable, since higher pressures yield better results. Thereafter the compressed and thus shaped body is tempered in vacuum or protective atmosphere such as nitrogen gas at about 900° C., for several hours, preferably at least 48 hours. The value of 48 hours as minimum period for the processing time is suitable. Very good results were obtained with periods of 50 to 60 hours. The tempering temperature must in any event remain below the melting temperature of gold (1,065° C.). The tempering temperature should be at least 825° C. with a temperature of about 900° C. having been found to be particularly favorable.

Thereafter, the boron content is determined of a portion of the pressed body, and the other portion is melted together with a correspondingly dimensioned quantity of
gold, and is thereafter rolled down to foil thickness. Suitably shaped pieces of this gold foil, produced for example by punching, are then placed upon the semiconductor body and allowed together therewith. The addition of the other alloying constituents may likewise be effected before melting the pressed body together with the gold. For example a portion of bismuth may be roasted, i.e., heated with ingress of air, and another portion of bismuth may be sulfurized, i.e., heated in pulverulent form together with sulfur flower to melting. After determining the oxygen and sulfur contents respectively, corresponding quantities of these two types of prepared bismuth are added to the tempered pressed material, if desired together with another portion of untreated bismuth. These melting operations are preferably also performed in vacuum or under protective gas.

We claim:
1. A method of producing boron-containing gold foil for p-doping a body of essentially monocrystalline silicon semiconductor material, comprising intimately mixing gold powder and boron powder, the mixture containing from 0.01 to 0.5% by weight of boron powder, compacting the mixture under a pressure between 10 and 100,000 atmospheres, tempering and sintering the compacted mixture at a temperature above 825°C and below the melting point of gold for a period of time sufficient to form a boron-gold alloy, subsequently melting the sintered, pressed boron-gold alloy, and thereafter forming the material into a foil.
2. The method of claim 1, the tempering being carried out in nitrogen gas.
3. The method of claim 1, the tempering being carried out in vacuum.
4. The method of claim 1, the tempering being carried out for at least a day, the compacting being carried out at at least 2,000 atmospheres pressure.
5. The method defined in claim 1, the boron-containing gold foil having from 0.001 to 0.02% of oxygen incorporated therein.
6. The method defined in claim 1, the boron-containing gold foil having from 0.001 to 0.01% of sulfur incorporated therein.
7. The method defined in claim 1, the boron-containing gold foil having 0.01 to 1% of bismuth incorporated therein.
8. A method of producing boron-containing gold foil for p-doping a body of essentially monocrystalline silicon semiconductor material, comprising intimately mixing gold powder and boron powder, the mixture containing from 0.01 to 0.5% by weight of boron powder, compacting the mixture under pressure, tempering and sintering the compacted mixture at a temperature below the melting point of gold for a period of time sufficient to form a boron-gold alloy, subsequently melting the sintered, pressed boron-gold alloy, and thereafter forming the material into a foil, the tempering being carried out for at least a day at a temperature of at least about 900°C, the compacting being at a pressure of at least 2,000 atmospheres.
9. A method of producing boron-containing gold foil for p-doping a body of essentially monocrystalline silicon semiconductor material, comprising intimately mixing gold powder and boron powder, the mixture containing from 0.01 to 0.5% by weight of boron powder, compacting the mixture under at least 10,000 atmospheres' pressure and tempering and sintering the compacted mixture for at least two days at a temperature of at least 825°C but below the melting temperature of gold, while under said pressure, subsequently melting the pressed body, and thereafter rolling the re-solidified material down to a foil.

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