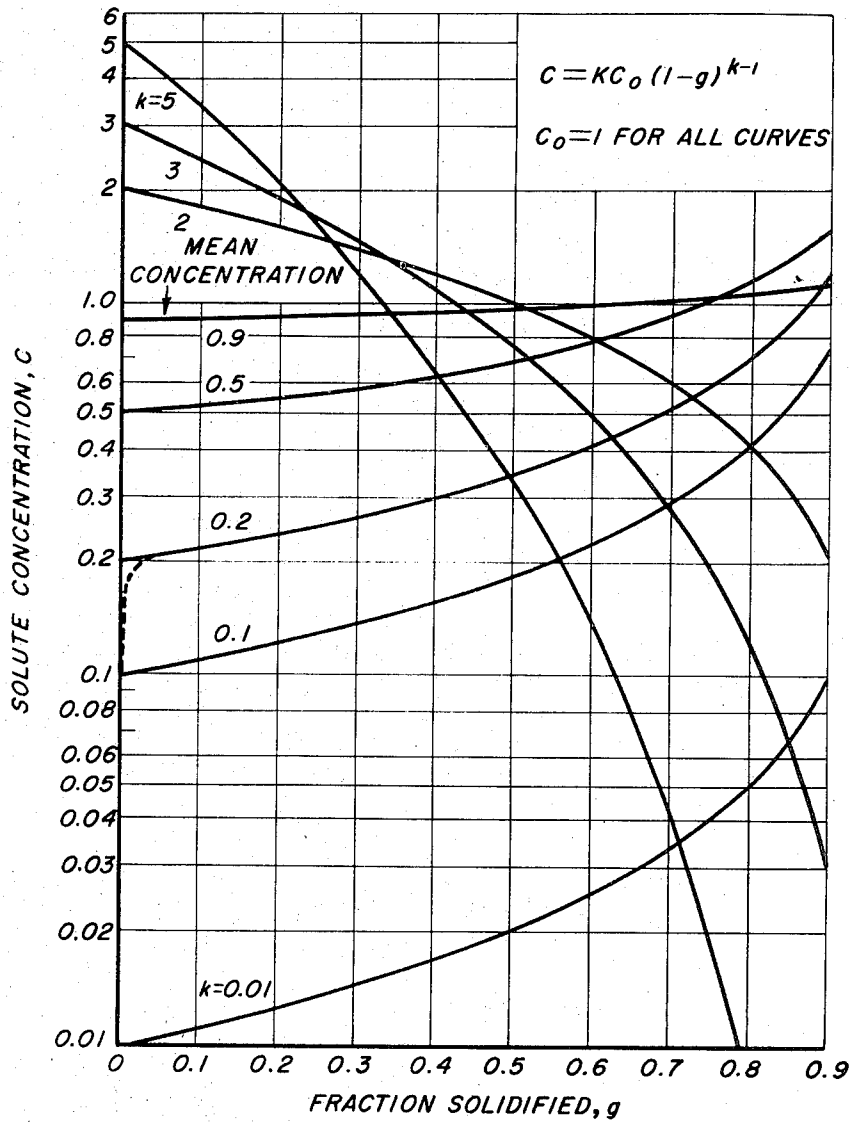


GALLIUM ARSENIDE

Original Filed April 19, 1966

2 Sheets-Sheet 1

FIG. 1



INVENTORS

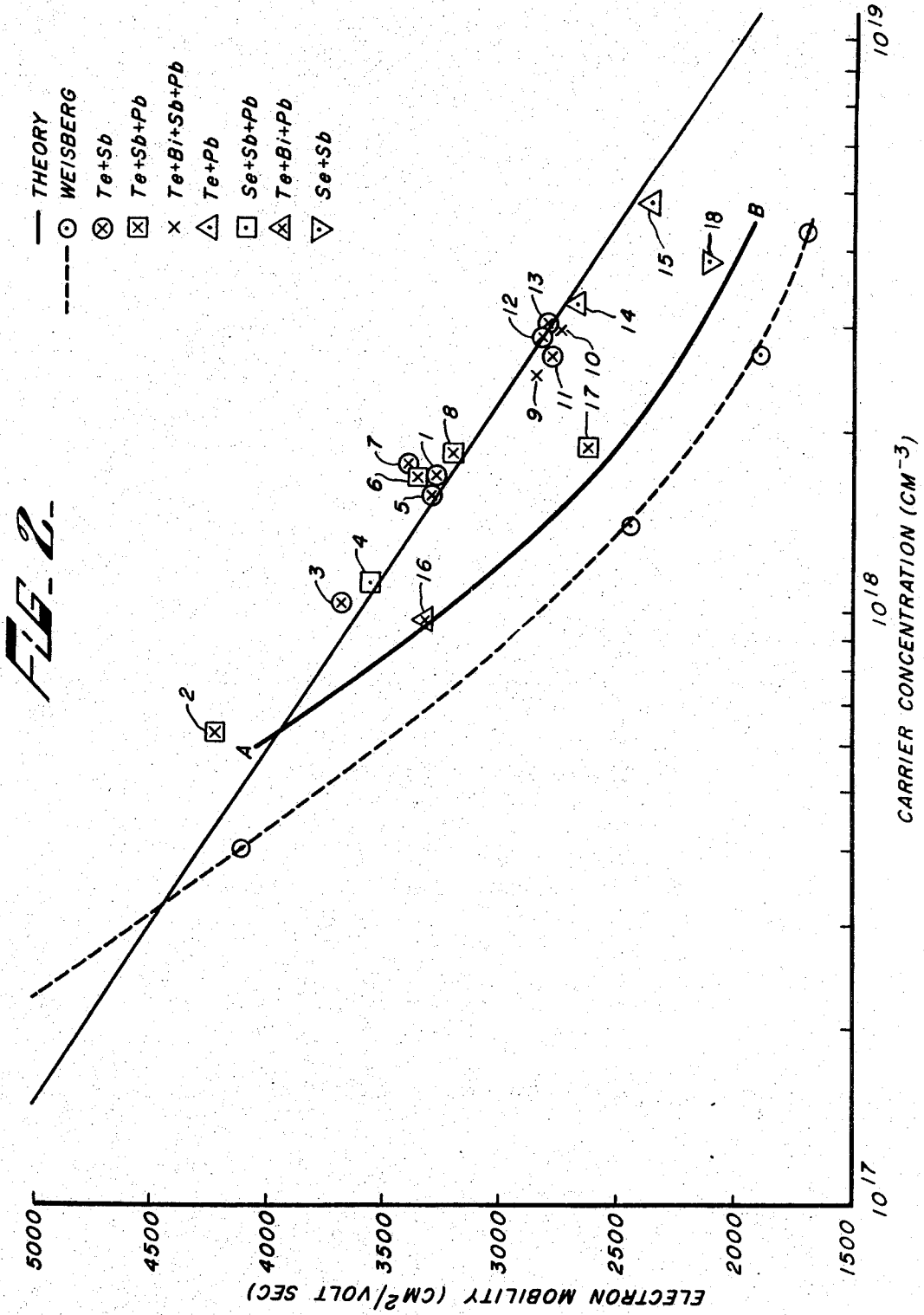
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GALLIUM ARSENIDE

Original Filed April 19, 1966

2 Sheets-Sheet 2



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3,630,906

GALLIUM ARSENIDE

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Continuation of application Ser. No. 543,604, Apr. 19, 1966. This application Oct. 2, 1969, Ser. No. 863,267

Int. Cl. C04b 35/00; C01b 27/00; B01j 17/00

U.S. Cl. 252-62.3 GA

1 Claim

ABSTRACT OF THE DISCLOSURE

Gallium arsenide having reduced lattice defect concentrations and enhanced electrical properties.

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of our application Ser. No. 543,604, filed Apr. 19, 1966, entitled "IIIB-VB Compounds," now U.S. Pat. 3,496,118.

BACKGROUND OF THE INVENTION

(1) Field of the invention

The fields of art to which the invention pertains include the fields of semiconductor materials and barrier layer device compositions.

(2) Description of the prior art

In recent years gallium arsenide and other IIIB-VB semiconductor compounds have been the subject of intensive investigation. Not only are they structural analogs of the semiconducting elements of the IV-B sub-group but even the chemical bonds between the atoms are remarkably similar. With appropriate doping, the electrical properties of these IIIB-VB compounds make them useful for a variety of semiconducting purposes, e.g., in light emitting diodes, high speed switching diodes, transistors and related devices where the electrical properties of the compound play an important role. Deviations from crystal lattice perfection detract from the crystal's electrical properties. Accordingly, it is desirable to obtain IIIB-VB semiconductor compounds having a reduced number of defects or deviations from crystal lattice perfection.

The problem of creating a nearly perfect semiconducting material is similar to that of obtaining a perfect and absolutely pure elemental single crystal with the additional difficulty of determining and maintaining perfect balance among two or more constituents. Initially all crystals have lattice defects in quantities dictated by their thermodynamic properties and the conditions under which they were formed and brought to room temperature. Seeding and growth conditions also determine the density of larger defects. Deviations from crystalline perfection in an otherwise chemically stoichiometric crystal may be caused by dislocations, stacking faults, boundaries, interstitial atoms, vacant lattice sites and/or misplaced atoms, and various combinations of these with each other and with impurity atoms. Departures from precise atomic structure can be determined by measuring the effects of the departure on the physical properties of the crystal, especially those properties involving the movement of atoms or electrons, as well as the electrical, magnetic and optical properties of the imperfections. Methods of making such determinations are known to those skilled in the art.

In one method of preparing single crystals of IIIB-VB compounds, the compound is contained in a crucible, or boat, together with an oriented seed crystal. A zone is melted between the seed and charge and is moved relative to the crucible. Either the crucible is moved past a

temperature gradient or a temperature gradient can be arranged to move past the crucible. In another technique, the floating zone method, a semiconductor rod is supported at its two ends and a small zone of the rod is melted and moved along the rod length. The molten section is supported by the surface tension of the liquid and by the solid parts of the rod. In still another method, a pulling, e.g. Czochralski method, a melt of the compound is contained in a crucible and a seed crystal is dipped in the free surface of the melt. The seed is slowly pulled out of the melt, usually with rotation, a crystal of the compound growing in length at the same rate the seed is withdrawn from the melt. The above and other methods are discussed in "Compound Semiconductors—Volume 1" (1962), edited by R. K. Willardson and H. C. Goering, published by Reinhold Publishing Corp., New York, which is hereby incorporated by reference.

The above techniques attempt to reach stoichiometry, or purify the compound while maintaining stoichiometry, by maintaining a melted section or portion of the compound at its melting point and stoichiometric dissociation pressure of the more volatile constituent. In all of the above methods, deviations occur during the growth of the crystal and substantially detract from its electrical properties. While chemical stoichiometry may be closely approached "physical" stoichiometry has not been closely attained. Thus, chemical analysis of the material may reveal a one-to-one correspondence of the elements involved, but imperfections or deviations from crystal lattice perfection occurring during the use of the above techniques prevent the crystal from being stoichiometric in the physical, i.e., lattice perfection, sense.

SUMMARY OF THE INVENTION

The present invention provides crystals of gallium arsenide with substantially reduced lattice defect concentrations, but with enhanced thermal conductivity and electrical properties yielding significantly improved device characteristics. A method is disclosed for providing such improved gallium arsenide which involves the addition to a melt of gallium arsenide of certain foreign elements or impurities which are occluded during crystal formation and which result in the growth of a more nearly perfect stoichiometric crystal containing an inconsequential amount of the foreign element or impurity and which is provided with enhanced electrical properties. Gallium arsenide of the structural purity and electrical characteristic as provided herein are novel compositions of matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plot of solute, or impurity, concentration against fraction of melt solidified; and

FIG. 2 is a plot of theoretical and experimental electron mobilities against carrier concentrations for carrier-atom-doped gallium arsenide formed by prior methods and by methods prescribed herein.

DETAILED DESCRIPTION

Stoichiometric group IIIB-VB compounds having a relatively low melting point, e.g., gallium antimonide and indium antimonide, have been prepared with relatively small deviations from crystal lattice perfection [D. Effer and P. J. Etter, J. Phys. Chem. Solids. 25: 451 (1964)]. However, with group IIIB-VB compounds having a melting point above 900° C., crystal lattice perfection has not been significantly approached. Thus, under the conditions in which zone melting techniques have been used, i.e., at the melting point of the crystal under a stoichiometric dissociation pressure of the more volatile constituent, those compounds containing impurities with small distribution coefficients will yield single crystals with uniform com-

position (e.g., page 279 of "Compound Semiconductors—Volume I," supra); but deviations from crystal lattice perfection, at least in compounds with melting points above 900° C., are still relatively high. Anomalies in the measured values of thermal conductivity at low temperatures as compared with theoretical predictions, indicate the presence of about $10^{19}/\text{cm}^3$ lattice defects in such IIIB–VB compounds supposedly "purified" by the above methods. [Pages 13, 18 and 31 of "Physics of III–C Compounds—Volume 2—Semiconductors and Semimetals" (1966), edited by R. K. Willardson and A. C. Beer, published by The Academic Press, New York, which is hereby incorporated by reference.] In the case of electrical conductivity, for carrier concentrations of about $1\text{--}2 \times 10^{18}/\text{cm}^3$ the experimental electron mobility values of gallium arsenide have been found to be 30 to 40% lower than predicted by theory [H. J. Ehrenreich, *J. Appl. Phys.* 32, 2155 (1961)]. Anomalous electrical conductivity results, obtained at room temperature, have been labeled "mobility killer phenomena" [L. R. Weisberg, *J. Appl. Phys.* 33, 1817 (1962)]. Calculations of the effect on mobility of lattice defects, which can behave as so-called neutral impurities, have been made [C. Erginsoy, *Phys. Rev.* 79, 1013 (1950); N. Sclar, *Phys. Rev.* 104, 1559 (1956)].

With prior methods, material to be treated is carefully chosen so that it contains a minimum of impurities, which often involves precise chemical analyses of many samples. The process described herein is similar to the above-described methods, but rather than using material containing a minimum of impurities, we purposely add impurities of a certain type, impurities that significantly lower the freezing point of the IIIB–VB compound; and the crystal is formed at that lower freezing point. This process is described and claimed in our above referenced application Ser. No. 543,604.

By our invention, gallium arsenide is provided with significantly decreased lattice defects and with properties of theoretical magnitude, whereas they have been previously unobtainable. For example, gallium arsenide having a carrier concentration from 10^{18} atoms of tellurium/ cm^3 can now be obtained with defect concentrations of less than $10^{16}/\text{cm}^3$; whereas with prior methods the defect concentrations for such a crystal were at least $10^{16}/\text{cm}^3$. By means of our invention, the electrical and thermal conductivities of doped gallium arsenide can be increased so that the determined values of electron mobilities are significantly enhanced and often correspond substantially with theoretical. For example, electron mobilities for tellurium-doped gallium arsenide obtained by this invention are in agreement with calculations using the Brooks Herring formula and an effective mass of 0.72 m. Increases in electron mobilities of as much as 40% can now be achieved, e.g., to 3300 $\text{cm}^2/\text{volt sec}$. for carrier concentrations of $2 \times 10^{18}/\text{cm}^3$. Gallium arsenide crystals having such enhanced characteristics were heretofore unknown; they constitute new compositions of matter.

Our invention can be more fully understood with reference to a prior method of "purifying" gallium arsenide. In prior methods, the gallium arsenide is heated at its melting point of 1238° C. in an evacuated or inert gas-filled closed chamber under 0.9 atmosphere of arsenic pressure. In a particular method of crystal formation, a pulling or Czochralski method, gallium is placed in a suitable crucible, e.g., of quartz, graphite, alumina, aluminum nitride, or the like, in a closed evacuated chamber containing sufficient arsenic to react with gallium to form gallium arsenide and an additional amount to maintain a stoichiometric dissociation pressure of arsenic, at the melting point of gallium arsenide, in the chamber; e.g., about 115–17 parts by weight of arsenic per 100 parts by weight of gallium. If doping of the material is desired, the dopant (e.g., about 0.05 to about 0.5 part by weight of tellurium per 100 parts of gallium) can be

placed on or below the gallium in the crucible. The crucible is heated to melt the gallium, and the dopant if present, and brought up to 1238° C. while the remainder of the chamber is heated so that the coolest point therein is at about 605° C. (so as to ensure an arsenic pressure of 0.9 atmosphere). A seed of gallium arsenide is lowered into the crucible and after contact with the melt is slowly raised, e.g., at about 0.01 to 2 mm./min. and at a relative rotational rate of about 5 to 50 r.p.m. A chemically stoichiometric crystal of gallium arsenide is formed; however, measurement of its electrical properties discloses the presence of substantially more than 10^{16} lattice defects/ cm^3 and, in lightly doped crystals, greater than 10 times as many lattice defects as carriers.

In a corresponding process of our invention, a similar procedure is followed except that an impurity as defined herein, e.g., 0.2 part by weight of antimony per 100 parts of gallium, is placed on or below the gallium in the crucible. The crucible is heated to melt the gallium and the impurity (and the dopant, if present) and brought up to the freezing point of the "impure" gallium arsenide. A melt of gallium arsenide forms in the crucible whereupon a crystal is grown as before, except at the lower freezing point resulting from the impurity. A chemically stoichiometric crystal of gallium arsenide is thereby formed and measurement of its electrical properties discloses the presence of less than 10^{16} lattice defects/ cm^3 and, in lightly, e.g., $5 \times 10^{15}/\text{cm}^3$, doped crystals, a carrier:lattice defect concentration ratio of at least about 1:10.

The above describes our process with regard to operation at the dissociation pressure of arsenic corresponding to the melting point of stoichiometric gallium arsenide. Our process can also be used at lower pressures with greater amounts of impurities to yield a greater decrease in freezing point. Similarly, smaller amounts of impurities, but at somewhat higher pressures can be used, yielding correspondingly smaller decreases in the freezing point.

It is also preferred that the method used to form the crystal involves pulling the crystal from its melt, e.g., in the manner of Czochralski, primarily because of easier handling. However, the other techniques are fully applicable provided, of course, that the conditions called for in the method of this invention are maintained.

In a preferred embodiment, the gallium arsenide treated by this invention contains a carrier concentration to which has been imparted increased electron or hole mobility properties, which concentration results from doping with appropriate carrier atoms, for example, manganese, tellurium, selenium, sulfur, cadmium, zinc, tin, germanium, silicon, mixtures thereof, and the like. Improvements in electron mobilities are obtained with gallium arsenide containing n-type dopants and treated by this invention, e.g., tellurium, selenium, sulfur, tin, germanium, and silicon. Improvements in hole mobilities are similarly obtained with p-type dopants such as manganese, cadmium and zinc. In general, improved electron mobilities are noted in gallium arsenide crystals of our invention when the carrier dopant concentration is at least about 2×10^{17} atoms per cm^3 and a particularly preferred concentration of carrier dopant is about 5×10^{17} up to about 5×10^{18} atoms per cm^3 .

The term "impurity" is limited to those elements, or compounds containing an element, which, during formation of the crystal from its melt, tend to concentrate in the liquid phase to give rise to a solid/liquid distribution coefficient of less than 1. In some cases it is desired to retain some of the impurities in the crystal, e.g., as dopants to impart particular conductivity or electron mobility properties. In this case, an impurity can be chosen having a distribution coefficient such that the solid gallium arsenide will contain the desired amount of impurity. In most cases it is desired to exclude the impurity from the solid, e.g., where chemically pure gallium arsenide is required or where the impurity would

interfere with or reduce the effect of a dopant material in the gallium arsenide. Here, impurities having distribution coefficients of appreciably less than one, preferably 0.02 or less, should be used. Elements are preferred as impurities but compounds can also be used. The distribution coefficient in gallium arsenide of various elements can be found in the literature or can be determined by methods known to those skilled in the art. Some of the techniques that can be used are discussed on pages 365-400 of "Compound Semiconductors—Volume 1," supra.

The following table lists some elements having reported distribution coefficients k of less than 1 in gallium arsenide, along with some reported ionization energies (E_i) in electron volts and conductivity types where "A" and "D" denote acceptor and donor impurities, respectively.

TABLE I

Element	Distribution coefficient k	Conductivity type	Ionization energy (E_i)
Aluminum	<0.2		
Antimony	<0.016		
Bismuth	0.0005		
Cadmium	0.009	A	0.020
Calcium	<0.02	A	
Carbon	0.8	D	
Chromium	0.00057		
Cobalt	0.00008		
Copper	<0.002	A	0.14
Germanium	0.02-0.03	D	
Indium	0.1		
Iron	0.002-0.003	A	0.037
Lead	<0.0002		
Magnesium	0.05-0.3	A	
Manganese	0.02-0.05	A	
Nickel	<0.02		
Selenium	0.3	D	
Silicon	0.14	D	<0.005
Silver	0.1	A	
Sulfur	0.3	D	
Tellurium	0.059	D	
Tin	0.08	D	
Zinc	0.12	A	0.014

Referring to Table I, it can be seen that many elements not only have distribution coefficients of less than one but also have coefficients of such small magnitude that the element would be substantially occluded from the crystal lattice.

The term "substantial occlusion from the crystal lattice" can be explained with reference to FIG. 1, where the change in solute, or impurity, concentrations with reference to the fraction of melt solidified is shown. With distribution coefficients k of less than one, segregation of the impurity results in an increase in solute concentration as more melt is solidified. Accordingly, even if the distribution coefficient were to remain the same at all solute concentrations, the greater concentration of impurity in later solidified fractions would result in higher impurity concentrations. On the other hand, some impurities do not follow the ideal curve of FIG. 1 but have a distribution coefficient that decreases as its concentration in the melt increases, so that uniformity of the ingot or solid is somewhat enhanced. The presence of a second impurity can modify the distribution coefficient of a first impurity so that the distribution coefficient of the first impurity increases (e.g., zinc) with the increased concentration of the second impurity (e.g., antimony). Thus, "lattice" in the term "substantial occlusion from the lattice" is meant generally to refer to that portion or portions of the crystal containing the desired impurity concentration.

The distribution coefficient is not the only parameter that should guide the choice of an impurity; other factors must be considered such as the diffusion coefficient of the impurity, whether it is a donor or acceptor type material in the gallium arsenide, etc., and these parameters and their effects are known to those skilled in the art. Thus, while an element such as copper has a low distribution

coefficient in gallium arsenide, the rapid diffusion of these elements might make them unsuitable in preparing stoichiometric gallium arsenide where the effect of diffusion could interfere with a desired property of the gallium arsenide. For example, while only a very small amount of copper would remain in gallium arsenide, the electrical properties of even such a small amount may preclude its use in favor of a material having less electrical effects even at a larger concentration. On the other hand, for some specific purpose it may be desired to have the electrical properties of a very small amount of copper, in which case copper might well be the impurity of choice.

Compounds can also be used as impurities, e.g., II-VI, II-IV-V, etc., compounds such as CdTe, CdS, CdSe, ZnGeAs, ZnSnAs, CdSnAs, and the like whose distribution coefficient or geometric properties will result in substantial occlusion of one or more of its elements from the solid.

Mixtures of impurities can also be used. If one of the impurities affects the ability of the gallium arsenide to dissolve the other impurity, an adjustment of distribution coefficient, or redetermination for the individual impurities under those conditions, should be made. Thus, if an impurity appreciably raises or lowers the freezing point of the gallium arsenide, a second impurity will generally have a somewhat different solubility at the new freezing point. Accordingly, when using mixtures of impurities, appropriate proportions should be determined and used. In an ideal system the distribution coefficient would be substantially temperature-independent, in which case only the amount of impurity added need be adjusted. This generally holds true for even non-ideal conditions where the temperature differences are small. With larger temperature differences there is generally a curved, rather than straight-line, relation between temperature and distribution coefficient.

In a preferred method of this invention the impurity added is such that it will be substantially occluded from the solidified gallium arsenide in terms of the distribution coefficient it is preferred that the impurity have a distribution coefficient of about 0.02 or less at the freezing point of the impurity-containing melt.

Notable examples of particularly effective elements are aluminum, bismuth, indium, antimony, lead, mixtures thereof in appropriate proportions, and the like.

An impurity concentration is used that significantly lowers the freezing point of the gallium arsenide. The term "significantly" refers to a magnitude such that a noticeable decrease in defect concentration is observed in comparison with material otherwise treated the same but without the presence of the impurity. The magnitude of freezing point decrease, and similarly the concentration of impurity to yield such decrease, required for an improvement in stoichiometry varies with compound and impurity, but is readily determined by making side by side determinations at varying levels of impurity concentrations. In general, it is preferred to add at least about 1×10^{18} atoms of impurity per cm^3 of compound and, as a practical matter, up to about 4×10^{21} atoms/ cm^3 .

The following examples illustrate advantages of our invention.

EXAMPLE 1

Using a Czochralski pulling apparatus similar to that shown in FIG. 29.5, page 260 of "Compound Semiconductors—Volume 1," supra, desired amounts of dopant and impurity are placed in a crucible and 100 grams of gallium are placed thereover. The crucible can be of quartz, graphite, alumina, aluminum nitride or the like, and sits in a sealable quartz chamber. A reservoir of 117 grams of arsenic are placed in the chamber which is evacuated and then sealed. A small amount, e.g., about 200 micrograms, of oxygen can be bled into the chamber prior to sealing. (A partial oxygen pressure has been found to somewhat aid the appearance of the crystal, but is not at all critical to the process.)

In one run, 0.24 gram of tellurium as dopant and 1.0 gram of antimony as impurity were used, along with a partial pressure from 200 micrograms of oxygen. The gallium and arsenic were obtained from the Eagle Picker Co. and Consolidated Mining Co., Ltd., respectively. The crucible was heated to melt the gallium, tellurium, and antimony. The remainder of the chamber was heated to above 605° C., but while maintaining a point in the chamber at 605° C. A melt of gallium arsenide formed in the crucible whereupon a seed crystal of gallium arsenide, oriented in the $\bar{1}\bar{1}\bar{1}$ direction, was lowered into the crucible and, after contact with the melt, was raised at about $\frac{1}{4}$ – $\frac{3}{4}$ inch per hour at a rotational rate of about 12 r.p.m. A crystal of gallium arsenide was thereby formed until the melt was exhausted.

A thin slice of the crystal was cut at about 10 grams from the top. Hall effect measurements revealed a carrier concentration of 1.71×10^{18} /cm.³. Electron mobility of the crystal portion was measured and found to be 3280 cm.²/volt sec.

EXAMPLES 2-18

The procedure of Example 1 was repeated with different dopants and impurities. The following tabulation describes various runs with tellurium or selenium dopants and with antimony, lead or bismuth impurities, or combinations thereof, in varying amounts. Carrier concentrations, obtained from Hall effect measurements, and electron mobilities are given for each run. Examples 6 and 8 are slices from different places in the same crystal. Example 11 is a slice from a different place in the crystal of Example 1 above.

Example	Dopant, gm.		Impurity, gm.			Partial O ₂ pressure, micrograms	Seed orientation	Pull rate, inches/hr.	Rotation rate, r.p.m.	Sliced, gms. from crystal top	Carrier concentration, cm. ³	Electron mobility, cm. ² /volt sec.
	Te	Se	Sb	Pb	Bi							
2	0.1		0.2	0.4		200	<1 1 1>	$\frac{3}{4}$	45	105	6.32×10^{17}	4,220
3	0.1		0.2			200	<1 1 1>	$\frac{3}{4}$	45	113	1.05×10^{18}	3,670
4		0.017	1.0	0.4		200	<1 1 1>	$\frac{3}{4}$	12	28	1.13×10^{18}	3,550
5	0.14		0.5			0	<1 1 1>	$\frac{3}{4}$	12	87	1.58×10^{18}	3,290
6	0.14		0.5	0.4		0	<1 1 1>	$\frac{3}{4}$	12	117	1.7×10^{18}	3,370
7	0.15		0.5	0.5		0		$\frac{3}{4}$	45	99	1.76×10^{18}	3,390
8	0.14		0.5	0.4		200	1 1 1	$\frac{3}{4}$	12	149	1.85×10^{18}	3,230
9	0.15		0.5	0.4	2.0	200	<1 1 1>	$\frac{3}{4}$	12	94	2.5×10^{18}	2,850
10	0.22		0.5	0.4	2.0	200	<1 1 1>	$\frac{3}{4}$	12	109	3.0×10^{18}	2,730
11	0.24		1.0			200	<1 1 1>	$\frac{3}{4}$	12	126	2.7×10^{18}	2,810
12	0.4		0.5			200		$\frac{3}{4}$	12	17	2.98×10^{18}	2,810
13	0.14		0.5			0	<1 1 1>	$\frac{3}{4}$	12	93	2.96×10^{18}	2,750
14	0.4			2.0		200	<1 1 1>	$\frac{3}{4}$	12	27	3.34×10^{18}	2,690
15	0.4			2.0		200	<1 1 1>	$\frac{3}{4}$	12	82	4.87×10^{18}	2,360
16	0.1			2.0	2.0	0	<1 1 1>	$\frac{3}{4}$	12	40	9.7×10^{17}	3,310
17	0.24		1.0	0.4		200	<1 1 1>	$\frac{3}{4}$	12	10	1.88×10^{18}	2,640
18		0.85	0.5			200	<1 1 1>	$\frac{3}{4}$	12	21	3.85×10^{18}	2,110

Referring to FIG. 2, the electron mobilities of the crystal slices in the above eighteen examples are plotted against carrier concentrations in those slices (the numbers in the drawing referring to the corresponding example number). Also plotted with encircled dots are the data of Weisberg et al., for gallium arsenide [J. Appl. Phys. 29: 1514 (1958)], connected with a dashed line. Theoretical values predicted by Ehrenreich, supra, are plotted as a solid line. It can be seen that the data obtained with the above eighteen experiments substantially correspond with theoretical values and in some cases are somewhat higher and reveal, indeed, that the slope of the solid line should be somewhat greater.

The term "enhanced" when used with electrical properties, such as electron mobility, refers to a magnitude that is significantly greater than the magnitude of such property for a corresponding crystal but grown by the prior art methods outlined above; i.e., by mere formation of the

crystal at the melting point of the compound at a stoichiometric dissociation pressure of arsenic without use of the impurity addition-occlusion technique described herein. The term "significant" refers to a magnitude that is greater than can be attributed to experimental error; referring to FIG. 2, gallium arsenides improved by this invention have, when containing a carrier dopant, electron mobilities relative to carrier concentrations that lie above the solid line AB.

As seen from FIG. 2, the electron mobility range, for the preferred range of carrier concentration of about 5×10^{17} to about 5×10^{18} atoms per cm.³, is from about 4,220 (Example 2) to about 1,875 (by extrapolation) cm.²/volt second.

A principal use of doped gallium arsenide is as the crystalline material used in presently known light emitting diodes, particularly lasers, in which the enhanced electrical and thermal conductivities, as well as other perfect or nearly perfect crystal properties, permit the fabrication of superior devices. Undoped gallium arsenide of this invention can be used in microwave oscillators, e.g., in Gunn effect type devices, well known in the art. Other uses for the doped and undoped gallium arsenide of this invention will be immediately apparent to those skilled in the art.

What is claimed is:

1. Gallium arsenide containing from about 5×10^{17} to about 5×10^{18} atoms per cm.³ of an n-type carrier dopant selected from tellurium, selenium, sulfur, tin, germanium, silicon and mixtures thereof, said gallium arsenide having an electron mobility relative to carrier concentration of from about 4,220 to about 1,875 cm.²/volt second, said

mobility lying above the solid line AB defined in FIG. 2 of the accompanying drawing.

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