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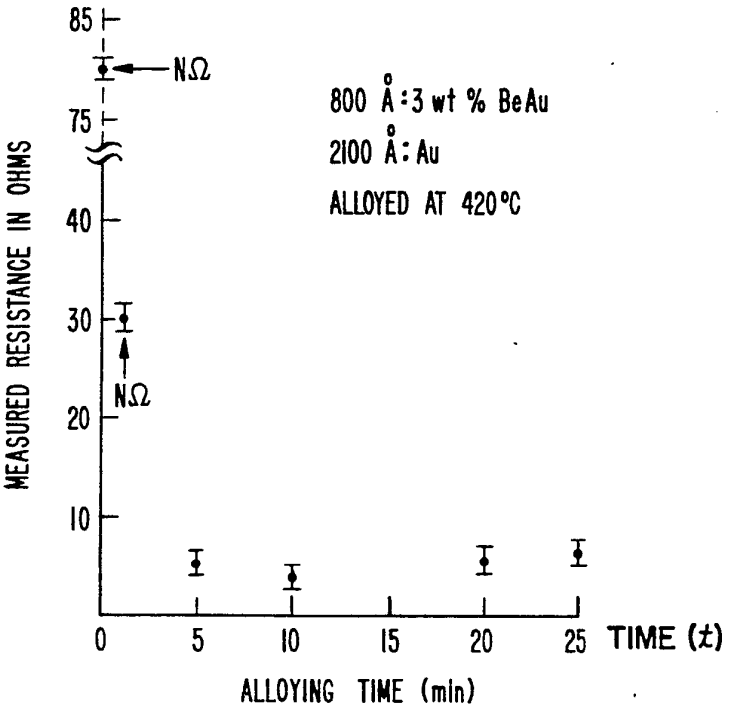
(54) **Title:** OHMIC CONTACT TO P-TYPE InP OR InGaAsP


(57) **Abstract**

Semiconductor device comprising a p-type InP or InGaAsP semiconductor material and an ohmic contact to a surface of the semiconductor material and a process for producing the same. The ohmic contact includes, in succession from the said surface, a layer of beryllium gold and a layer of gold. The surface containing the layers is heat-treated at a temperature of 440°C or less for a residence time of at least one minute. Optionally, a layer of palladium may be positioned intermediate the surface and the beryllium-gold layer permitting heat-treatment at lower temperatures e.g., less than 420°C.

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# Ohmic Contact To P-Type InP or InGaAsP

## Technical Field

This invention is concerned with a method of making ohmic contacts to p-type InP and InGaAsP, and to semiconductor devices having such contacts.

## Background of the Invention

Successful semiconductor device fabrication and operation frequently requires contacting the semiconductor device with low resistance ohmic contacts. Problems often arise in attempting to fabricate and use such contacts. For example, the contacting material may form a rectifying, rather than ohmic, contact with the semiconductor material, or it may not reliably bond to the semiconductor material, and physically unreliable electrical contacts result.

Group III-V semiconductor compounds are of much interest today, and much effort has been directed toward developing reliable ohmic contacts with such compounds. Many processes for fabricating low resistance ohmic contacts to such compounds are known. These processes typically involve the deposition of one or more layers and may or may not involve one or more heat treating steps. U.S. Patent 3,214,654 describes ohmic contacts to Group III-V compounds which are formed by a layer of a metal selected from the group consisting of silver, gold, ruthenium, rhodium, palladium, osmium, irridium and platinum and a layer of either nickel or cobalt. Germanium-palladium contacts to n-type Group III-V compounds are described by U.S. Patent 4,011,583.

Particular interest has recently been shown in Group III-V compounds that are useful in optical devices, such as light emitting diodes, lasers and photodetectors, that operate at wavelengths longer than 1.00 micrometers. It should be understood that the term "light," as used in this specification, includes both the visible and the

near infrared portions of the electromagnetic spectrum. Interest in devices that operate in this region has arisen primarily because the silica-based optical fiber compositions presently contemplated for optical communication systems have smaller material dispersion, as well as low loss, about 1.00 micrometer than they do below 1.00 micrometer.

One class of light emitting devices presently contemplated for such systems uses the quaternary alloy, InGaAsP, which is grown on InP. Such devices are useful between 0.95μm and 1.68μm. These light emitting devices operate at high forward current and require high quality ohmic contacts to reduce series resistance. For this class of devices, as well as others, ohmic contacts to InP are necessary.

While low resistance ohmic contacts to n-type InP can now be easily fabricated, the formation of ohmic contacts to p-type InP still presents difficulties. P-type contacts to InP have been made using Zn as the acceptor. While these contacts are quite acceptable for many purposes, they have a number of drawbacks. For example, Journal of Applied Physics, 46, pp. 452-453 (1975) reports a rather high resistance, namely, $10^{-3}$ ohm.cm$^2$, for an electroplated Au/Zn/Au metallization. Furthermore, additional problems arise when Zn is used as the acceptor because the relative volatility of Zn makes it difficult to fabricate the contact with vacuum deposition techniques. Moreover, rapid diffusion of the Zn through the InP, together with the high doping concentrations required, may cause either junction motion or long-term device reliability problems or both.

Ohmic contacts to some Group III-V compounds using Be-Au metallizations, i.e., Be is used as the acceptor, are known. For example, such metallizations have been made to p-type GaP. However, formation of these ohmic contacts has required heating the GaP devices to the

relatively high temperature of 600 degrees C for approximately 5 minutes to form the ohmic contact. Alloying temperatures of 600 degrees C cannot be used to form ohmic contacts to either InP or InP containing devices because InP begins to decompose through P outdiffusion at approximately 400 degrees.

Summary of the Invention

We have found that ohmic contacts having low resistance can be made to p-type InP material in a semiconductor device by using beryllium as the acceptor. The contact is formed by sequentially depositing, on the InP, a 1 to 3 percent, by weight, beryllium in gold (Be-Au) composition and a gold overlay. The deposition is followed by heat treating the deposited material at a temperature less than 440 degrees C for a time of at least 1 minute. Deposition of a palladium layer on the InP layer prior to the deposition of the Be-Au layer permits use of a heat treating temperature less than 420 degrees C but generally results in a contact with a slightly higher resistance. This method may also be used to produce a low resistance ohmic contact to p-type InGaAsP.

Brief Description of the Drawing

FIG. 1 is a cross-sectional view of a device processed according to this invention.

FIG. 2 plots alloying temperature, horizontally, versus resistance in ohms, vertically, for a contact of this invention; and

FIG. 3 plots alloyint time, horizontally, versus resistance in ohms, vertically, for a contact of this invention.

Detailed Description

FIG. 1 shows a semiconductor device having a semiconductor layer 10. Layer 10 may be a substrate, but is more typically an epitaxial layer grown on a substrate. The semiconductor device may be a light emitting diode, laser, etc. Metal layers 20, 30 and 40 are sequentially

deposited above layer 10 and form the ohmic contact after heat treating. The semiconductor device further comprises additional semiconductor materials (not shown) deposited on layer 10 opposite layer 20. Layer 10 consists of InP. Layer 20 consists of palladium, layer 30 consists of a beryllium-gold composition, and layer 40 consists of gold. For reasons that will be explained, the presence of layer 20 is optional. If layer 20 is omitted, layer 30 is deposited directly on the substrate. The InP layer may be covered with an InGaAsP layer prior to deposition of layer 20, in which case the ohmic contact is made to the InGaAsP layer. Conventional techniques, such as electron gun evaporation, may be used to deposit the layers. Beryllium has a vapor pressure very similar to that of gold and can, therefore, be evaporated very reproducibly from beryllium-gold sources. Pressures are desirably held below $6 \times 10^{-5}$ torr.

Conventional p-type dopants may be used in the InP substrate. For example, Zn, with a concentration of $8 \times 10^{18} cm^{-3}$ may be used in a liquid-encapsulated Czochralski (LEC) grown substrate. The particular p-type dopant used is not critical to formation of an ohmic contact with this invention. The dopant concentration should, however, be at least $10^{17} cm^{-3}$ to form an ohmic contact. The dopant concentration should be as high as is practical because resistance decreases as the dopant concentration increases. The method of substrate growth and the substrate orientation are both noncritical.

Layer 20 is optional and when present, is approximately 100Å (10 nanometers) thick. A layer of 100Å (10 nanometers) is sufficiently thick to trap outdiffusing P through formation of intermetallic P-Pd compounds without impeding Be migration into the InP substrate. Thicker layers may result in the formation of undesired Pd compounds. This layer permits, as subsequently described, lowering of the heat treating or alloying temperature and, therefore, reduction of the InP tendency for thermal dissociation. There may, however,

be a slight increase in contact resistance when the Pd layer is present.

Layer 30 consists of a gold beryllium composition having between 1 and 3 percent, by weight, beryllium. The described weight percent range of Be is desirable because Be and Au form well-defined structures within this range. Layer 30 is typically 800A (80 nanometers) thick, although thicknesses as small as 600A (60 nanometers) and as large as 1000A (100 nanometers) may be used. Below 600A, (60 nanometers) there may not be sufficient Be for the reaction, and above 1000A, (100 nanometers) too much Be may be present. The presence of too much Be makes contact formation difficult as the reaction is driven by Au. A Be content of 3 percent is preferred over 1 percent because at the lower weight percent, contact uniformly is not as good.

Gold layer 40 is at least 2100A (210 nanometers) thick and may be thicker if so desired. However, if layer 40 is thinner, the contact may not be uniform and smooth after heat treating. The minimum thickness is conveniently used.

After deposition of the layers, the structure is heat-treated at a temperature less than 440 degrees C for a residence time of at least 1 minute. If the palladium layer is not present, the preferred range for heat treating is between 400 degrees C and 440 degrees C, and the residence time is between 5 and 10 minutes. If palladium layer 20 is present, the alloying temperature is preferably less than 420 degrees C, and the residence time is at least 1 minute. The preferred heat treating temperature is approximately 400 degrees C. Temperatures outside the above range have higher contact resistances, and are, therefore, less preferred.

Heat treating conveniently takes place in any of the conventionally used atmospheres such as forming gas (a hydrogen-nitrogen mixture), argon or nitrogen.

Alloying or heat treating times and temperatures may be determined with more specificity by reference to

FIGS. 2 and 3 which show the measured resistance as functions of treating temperatures and times, respectively.

FIG. 2 plots alloying temperature in degrees centigrade, horizontally, versus resistance in ohms, vertically, for contacts having an 800A (80 nanometers) thick 3 weight percent Be in Au layer, and a 2100A (210 nanometers thick Au layer. The open circles represent contacts with a 100A (10 nanometers) thick Pd layer, and the solid circles represent contacts in which a Pd layer was not present. The contacts were alloyed for 10 minutes. The contact resistances are a minimum between 400 and 440 degrees C without the Pd layer. With the Pd layer present, temperatures equal to or above 375 degrees C may be used.

It is hypothesized that lower heat treating temperatures can be used with the palladium layer because the palladium layer traps outdiffusing phosphorous and forms intermetallic palladium-phosphorous compounds. The resistance obtained by this scheme is generally slightly greater than that obtained without the palladium layer. However, the ohmic contact can be formed adequately, i.e., with an acceptably small resistance, at a temperature as low as 375 degrees C compared to the approximately 400 degrees C needed if the palladium layer is not present. At 375 and 400 degrees C, the resistances are approximately 10 and 5 ohms, respectively.

FIG. 3 plots alloying time in minutes, horizontally, versus resistance in ohms, vertically, for contacts having an 800A (80 nanometers) 3 weight percent Be in Au layer and a 2100A (210 nanometers) Au layer. The contacts were alloyed at 420 degrees C. The contact resistances are a minimum for alloying times between 5 and 10 minutes. Heat treating times outside this range lead to higher resistances, especially for shorter times. Longer times are not preferred because of the increased possibility that undesired intermetallic compounds may

be formed in addition to the possibility of InP decomposition.

Example: A double heterostructure InP/InGaAsP/InP light emitting diode was grown by liquid phase epitaxy on a (100) oriented n-type InP substrate and consisted of a buffer layer approximately 2 micrometers thick Sn doped, ($n = 10^{18} cm^{-3}$), a 1-micrometer thick active InGaAsPlayer ($n = 2 \times 10^{16} cm^{-3}$), and a Zn-doped ($n = 10^{18} cm^{-3}$) p-type InP layer having thickness of 1.5 micrometers. An ohmic contact was made to the p-type layer as described above. The contact was a 50 micrometer dot. The contact to the n-type layer was a horseshoe-shaped sandwich of Au-Sn-Au about 5000Å (500 nanometers) thick. At a current of 60 mA and a forward voltage of approximately 1.5 eV, and power emitted into the air was approximately 3 mW. This corresponds to a power conversion efficiency of approximately 3 percent. The upper limit of specific contact resistance was $7.8 \times 10^{-5}$ ohm.cm. This value is approximately two orders of magnitude lower than specific resistances previously reported for Au-Zn contacts to InP.

CLAIMS

1. A semiconductor device comprising a p-type InP or InGaAsP semiconductor material and an ohmic contact to a surface of the semiconductor material,

CHARACTERIZED IN THAT

said ohmic contact includes, in succession from the said surface, a layer of beryllium-gold and a layer of gold.

2. A semiconductor device according to claim 1,

CHARACTERIZED IN THAT

said ohmic contact further comprises a layer of palladium intermediate the said surface and the beryllium-gold layer.

3. A semiconductor device according to claim 1, or 2,

CHARACTERIZED IN THAT

said beryllium-gold layer contains prior to a heat treatment, from 1 to 3 weight percent of beryllium.

4. A method of producing an ohmic contact to a semiconductor device, which comprises a p-type InP or InGaAsP semiconductor material, by depositing at least one metal layer on a surface of the material and heat treating the device,

CHARACTERIZED IN THAT

said at least one metal layer includes, in succession from the surface, a layer of beryllium-gold and a layer of gold, and the said heat treating is conducted at a temperature of $440^{o}$ C or less for a resistance time of at least one minute.

5. A method according to claim 4,

CHARACTERIZED BY

using a beryllium-gold layer containing from 1 to 3 weight percent of beryllium.

6. A method according to claim 5,

CHARACTERIZED BY

depositing said beryllium-gold layer in a thickness of from 60 to 100 nanometers (600 to 1000Å)

preferably 80 nanometers (800A).

7. A method according to claim 4,
CHARACTERIZED BY
conducting said heat treating at a temperature ranging from 400 to 440 degrees C.

8. A method according to claim 4,
CHARACTERIZED BY
optionally depositing upon said surface and prior to said beryllium-gold layer, a palladium layer approximately 10 nanometers (100A) thick.

9. A method according to claim 8,
CHARACTERIZED BY
conducting said heat treating at a temperature ranging from 375 and 420 degrees C, preferably at a temperature of 400 degrees C.

10. A method according to any one of preceding claims 4, 5, 6, 7, 8 or 9,
CHARACTERIZED BY
depositing said gold layer in a thickness of at least 210 nanometers (2100A).

1.

FIG. 1

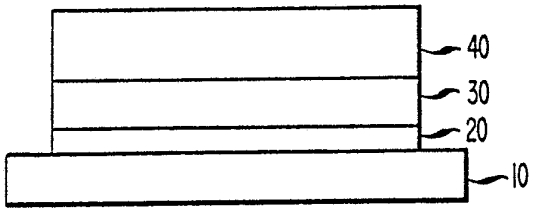



FIG. 2

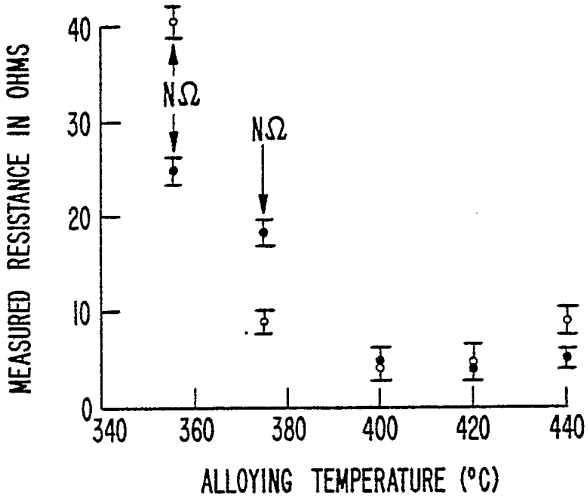
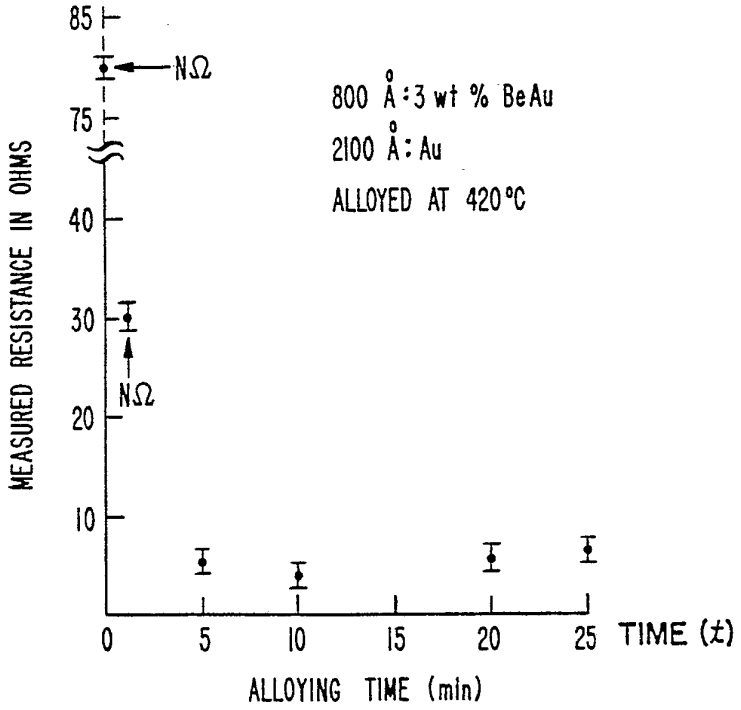



FIG. 3



# INTERNATIONAL SEARCH REPORT

International Application No PCT/US80/01079

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[3] H01L 23/48, 29/40, 29/54,
U.S. CL. 357/65, 67, 71; 29/588, 590

**II. FIELDS SEARCHED**

Minimum Documentation Searched [4]

| Classification System | Classification Symbols |
|---|---|
| US | 357/65, 67, 71; 29/588, 590 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

**III. DOCUMENTS CONSIDERED TO BE RELEVANT** [14]

| Category * | Citation of Document, [16] with indication, where appropriate, of the relevant passages [17] | Relevant to Claim No. [18] |
|---|---|---|
| A | US, A, 3,214,654, Published 26 OCTOBER 1965, ARMSTRONG ET AL | 1-10 |
| A | US, A, 3,598,997, Published 10 AUGUST 1971, BAERTSCH | 1-3 |
| A | US, A, 3,616,406, Published 26 OCTOBER 1971, TURNER | 1-10 |
| X | US, A, 3,620,847, Published 16 NOVEMBER 1971, WISE | 1-3 |
| A | US, A, 3,768,151, Published 30 OCTOBER 1973, MARINACE | 1-10 |
| X | US, A, 3,942,244, Published 9 MARCH 1976, FLOHRS ET AL | 1-10 |
| X | US, A, 3,987,480, Published 19 OCTOBER 1976, DIGUET ET AL | 1-10 |
| A | US, A, 4,011,583, Published 8 March 1977, LEVINSTEIN ET AL | 1-10 |
| A | US, A, 4,064,621, Published 27 DECEMBER 1977, LO | 4-10 |
| X | US, A, 4,068,022, Published 10 JANUARY 1978, GLICK | 1-10 |

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**IV. CERTIFICATION**

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|---|---|
| 29 DECEMBER 1980 | 05 JAN 1981 |
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