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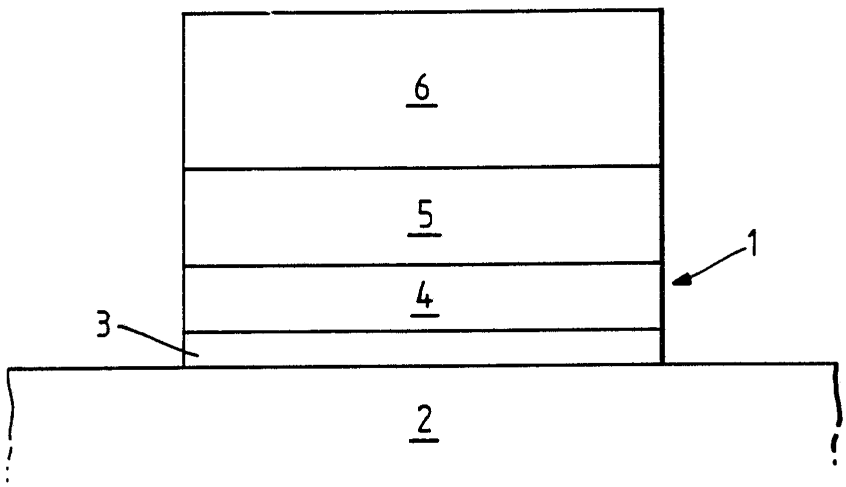

(57) Abstract

A low resistance ohmic contact for n-type GaAs and GaAlAs is provided by Ni-Ge-Au structure (1). The contact is suitable for device substrates (2) which have carrier concentrations of between about 10^{17} cm^{-3} and about 10^{19} cm^{-3}. The ohmic contact has a nickel layer of between 40 Å and 200 Å deposited on the substrate, followed by a Ge deposition (4) of between 150 Å and 400 Å and finally an Au deposition (5, 6) of greater than 4000 Å. The Au layer is preferably deposited in two separate layers of between 500 Å and 1000 Å, (5), and greater than 4000 Å, (6). A preferred construction (1) is 50 Å/200 Å/800 Å + 5000 Å (Ni/Ge/Au + Au). The ohmic contact deposition must be followed by annealing, typically at temperatures between 300 °C and 500 °C for times of between 1 second and 200 seconds. The preferred annealing conditions are a temperature of 400 °C maintained for 15 seconds.

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OHMIC CONTACTS FOR GaAs AND GaAlAs.

This invention relates to ohmic contacts used on n-type GaAs and GaAlAs devices.

GaAs and GaAlAs are preferred materials for the manufacture of high speed devices such as bipolar transistors, heterojunction bipolar transistors or high mobility electron transistors. However, for efficient use of the higher device operating speeds of such materials, it is necessary to minimise the resistance of the ohmic contacts. Lower ohmic contact resistances lead to a reduction in undesirable heat production, improved frequency response and an increase in noise immunity for logic circuits.

Alloyed Ge-Au and Ni-Ge-Au films are widely used for fabricating ohmic contacts to n-type GaAs. In general, adding small amounts of Ni to Ge-Au leads to lower contact resistance as well as serving to maintain a smooth surface morphology after alloying the contact metallisation.

Heime et al (Sol. St. Electronics 17 pp835-837 1974) have reported specific contact resistivities of $4 \times 10^{-4}\Omega cm^2$ for carrier concentrations of $2 \times 10^{15} cm^{-3}$ and $1 \times 10^{-6}\Omega cm^2$ for carrier concentrations of $1 \times 10^{18} cm^{-3}$. These values were achieved using contacts where a 50A layer of Ni was evaporated onto GaAs, with a 700A layer of eutectic AuGe laid on the nickel and a final 300A Ni overplate evaporated onto the AuGe.

In 1987 Rai et al (J. App. Phys. 61(9) pp4682-4688 1987) were able to achieve an ohmic contact resistance minimum of about 0.2Ω-mm after an alloy anneal of 420°C. Their ohmic contact metallised structure consisted of sequential electron beam deposited layers of 50A Ni; 170A Ge; 300A Au; 150A Ni; and 2000A Au. This contact definition was deposited on n^+ GaAs. A direct comparison of this reported ohmic contact resistance with that of the contacts reported by Heime et al is difficult due to the fact that Heime et al did not report the sheet resistance of the substrate material.

Further reductions in ohmic contact resistance are reported in J. Vac. Sci. Technol. B4(4) pp903–911 1986 by Murakami et al. Three different ohmic contact constructions were detailed, each deposited on GaAs implanted to contain 1 x $10^{18}cm^{-3}$ carriers. The mean contact resistance of each type of contact construction was about 0.1Ω-mm or slightly greater. Type A sample was prepared by sequentially depositing a 1000A Au–Ge layer followed by 350A Ni and 500A Au layers. Sample types B and C were prepared by depositing 50 and 100A of Ni, respectively, as the first layer, followed by Au–Ge (1000A thick), Ni (300A and 250A thick respectively) and Au (500A thick) layers.

Ohmic contacts may also be made to n–type GaAlAs layers by the use of a thin buffer GaAs contact layer. The buffer layer prevents oxidation of Al and also helps to improve adhesion.

The object of this invention is to provide ohmic contacts with reduced contact resistance, and hence ohmic contacts which are more suitable for n–type GaAs and AlGaAs device fabrication. The invention may be produced by the use of conventional GaAs and AlGaAs technology.

According to this invention a low resistance annealed ohmic contact for n–type GaAs and GaAlAs comprises:–

multiple layers of Ni–Ge–Au ohmic contacts on n–type GaAs substrate of GaAlAs substrate with a thin buffer GaAs contact layer,

characterised by:–

a first layer of Ni of thickness between 40A and 200A deposited on the substrate, a second layer of Ge of thickness between 150A and 400A and a third layer of Au of thickness greater than 4000A.

A preferred method of construction is to form the gold layer in two separate gold layers, the first being between 500A and 1000A thick and the second being a minimum of 4000A thick.

Following the laying down of the contact metallisation it is necessary to anneal the contact. This process is used to alloy the laid down metallisation into the substrate to give the required ohmic behaviour and a low contact–substrate contact resistance. Typical annealing temperatures are between 300°C and 500°C. The contact is annealed for a length of time of between 1 second and 200 seconds. Preferred annealing conditions are a temperature of about 400°C maintained for about 15 seconds.

Suitable methods of producing the ohmic contacts include electron beam evaporation thermal evaporation and sputter coating. The preferred method for the production of ohmic contacts is that of using electron beam evaporation to deposit the nickel, germanium and first gold layers. In this first evaporation sufficient gold is deposited to protect the nickel and germanium layers from the ambient environment outside the evaporation equipment. This is followed by a second electron beam evaporation or thermal evaporation process to deposit the thicker second layer of gold. The second layer is most conveniently carried out in a separate electron beam evaporator which is designed to prevent overheating of the substrate and eliminate spitting of gold during evaporation.

The preferred construction of an ohmic contact for n–type GaAs is 50A/200A/800A + 5000A (Ni/Ge/Au + Au).

The purity of the contact materials prior to use is typically about 99.999%.

Typical carrier concentrations for GaAs and GaAlAs substrate suitable for this construction of ohmic contact are in the range of $10^{17}cm^{-3}$ and $10^{19}cm^{-3}$.

The invention will now be further described by example only with reference to the following figures:

Figure 1 is a cross section of a preferred ohmic contact construction.

Figure 2 is a schematic representation of electron beam evaporation apparatus used to lay down ohmic contact material.

Figure 3 is a schematic representation of a rapid anneal system.

Figure 4 is a histogram of a typical spread of contact resistance values achieved by using the described technique.

Figure 5 is a histogram of a typical spread of specific contact resistivity values achieved by using the described technique.

A cross section of the preferred construction of ohmic contact 1 may be seen in figure 1. Material for device substrate wafer 2 is typically Si doped n-type GaAs, with carrier densities of about 2 x $10^{18}cm^{-3}$, as characterised by Hall measurements. Sequential layers of 50A nickel, 3, 200A germanium, 4, and 800 + 5000A gold, 5 and 6, are deposited by an electron beam evaporation process.

Prior to ohmic pattern definition, substrate wafers are cleaned with a solvent spray for 60 seconds, suitable cleaning solvents being acetone or isopropyl alcohol. After cleaning the definition of areas of the substrate wafer onto which the ohmic contacts are to be deposited is carried out, often by a process such as lithography. At this point the wafer may be either stored for future processing or alternatively be used immediately in the ohmic contact deposition process.

The first step in the ohmic contact process is the deoxidation of the wafer 2. This may be carried out in a bath of 10% NH_4 in deionised water for approximately 30 seconds. The wafer is then dried, most conveniently by blowing nitrogen gas over the substrate, and transferred onto a jig. The jig is placed in an electron beam evaporator, such as may be seen schematically in figure 2. The drying and transfer of the wafer into the evaporator is carried out as quickly as possible in order to minimise the reoxidation of the wafer surface in the free environment.

Figure 2 is a schematic representation of an electron beam evaporator 10 which may be used depoit nickel, germanium and gold layers on wafer 2. Jig 11, which is carrying the wafer, is placed on a holder 12. The evaporator is pumped down by pump 22 to a vacuum of 10^{-6} Torr or better. Slugs of nickel 13, germanium 14, and gold 15 are each held in vitreous graphite crucibles 16.

The crucibles are each held in a locator 17 which are attached to a carousel 18. Directly above one of the locators there is an electron beam source 19.

The carousel 18 is rotated to place the nickel bearing crucible under the electron beam source. To achieve sufficient power density to melt the metals the carousel is raised such that the graphite crucible is near the electron source. The electron beam source 19 is then turned on and the nickel heated. Monitoring of the deposition rate and thickness of material is carried out by the use of crystal monitor 20. The wafer 2 is protected from the evaporated material by shutter 21. When the laying down rate is sufficiently high (typically about 10A per second), the shutter is rotated away to reveal the wafer surface to the evaporated material. The thickness of the deposited material is monitored by the crystal monitor, with the shutter rotated back to shield the wafer 2 when 50A of nickel has been laid down. The source is then turned off and the carousel lowered and rotated to place the germanium bearing crucible under the electron beam source. The evaporation process is then repeated to deposit 200A of germanium. The same steps are also followed for evaporation of a 500A gold layer, except that the deposition rate is controlled to be about 5A per second due to the increased tendency for gold to spit during evaporation.

After returning the evaporator 10 to ambient air pressure, the jig 11 holding wafer 2 is transferred as quickly as possible to another electron beam evaporator, which is also then pumped down to a vacuum of 10^{-6} Torr or better. The second electron beam evaporator is preferably a large evaporator which is capable of ensuring that the wafer is not overheated during the deposition of the thick gold layer and also of eliminating the likelihood of the gold spitting during the evaporation process. The evaporation conditions for the second gold layer are as described above for the deposition of the first gold layer.

Figure 3 shows schematically a rapid thermal anneal system 30. The system is used to alloy the deposited metallisation into the substrate 2 to give the required ohmic behaviour and a low contact–substrate resistance. Following deposition of the nickel, germanium and two gold layers, the wafer 2 is taken off the jig 11 and placed, with the uncontacted surface uppermost, on a silicon holder 31 which has an integral thermocouple 32. The silicon holder is then placed in the rapid anneal system with the contact layers on the wafer surface facing downwards. The thermocouple is then attached to a temperature monitoring and controlling unit 33. The laminar flow of nitrogen gas is fed through the rapid anneal system and two banks of infrared lamps 34(a) and 34(b) are energised by power source 35. The monitoring and control unit is then programmed to allow the lamps to heat the silicon holder to a temperature of between 300°C and 500°C (as measured by the thermocouple) at a rate of about 130°C and to maintain the designated temperature for a time of between 1 second and 200 seconds. The preferred conditions of anneal is a temperature of about 400°C held for about 15 seconds. At the end of the anneal the lamps are turned off and the silicon holder and wafer allowed to return to room temperature.

Contact quality is assessed on transmission variable gap structures fabricated on the substrate wafers such as wafer 2. By using a computer controlled autoprobing facility all such structures across a wafer may be measured for both contact resistance and specific contact resistivity.

Figure 4 is a histogram showing typical distribution of contact resistance (Ω-mm) of ohmic contacts of the preferred metallisation scheme on a typical n-type GaAs substrate of carrier concentration 2 x $10^{18}cm^{-3}$. The contacts were manufactured using the processing steps described above. The mean contact resistance is about 0.045Ω-mm.

Figure 5 is a histogram of a typical distribution of specific contact resistivity (Ω-cm^2) of ohmmic contacts of the preferred metallisation scheme on a typical n-type GaAs substrate of carrier concentration 2 x $10^{18}cm^{-3}$. The contacts were manufactured using the process steps described above.

CLAIMS

1. A low resistance annealed ohmic contact for n-type GaAs and n-type GaAlAs comprising:-

multiple layers of Ni-Ge-Au contacts on n-type GaAs substrate and n-type GaAlAs substrate with a thin buffer GaAs contact layer,

characterised by

a first layer of Ni of thickness between 40A and 200A deposited on the substrate, a second layer of Ge of thickness between 150A and 400A and a third layer of Au thickness greater than 4000A.

2. An ohmic contact according to claim 1 where the contact has a Ni layer of 50A, a Ge layer of 200A and a gold layer of two separate layers of 800A and 5000A.

3. An ohmic contact according to Claim 1 where the annealing is carried out at a temperature of between 300°C and 500°C and for a time of between 1 second and 200 seconds.

4. An ohmic contact according to claim 2 where the annealing is carried out at a temperature of about 400°C for about 15 seconds.

Fig. 1.

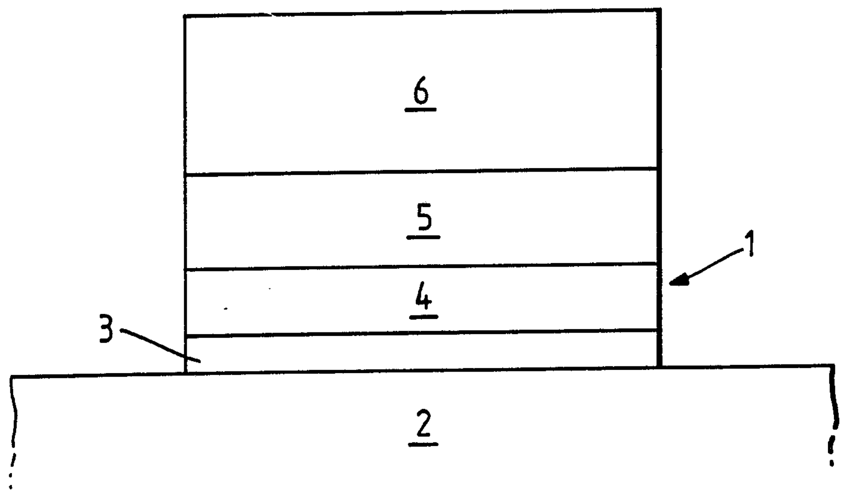


Fig. 3.

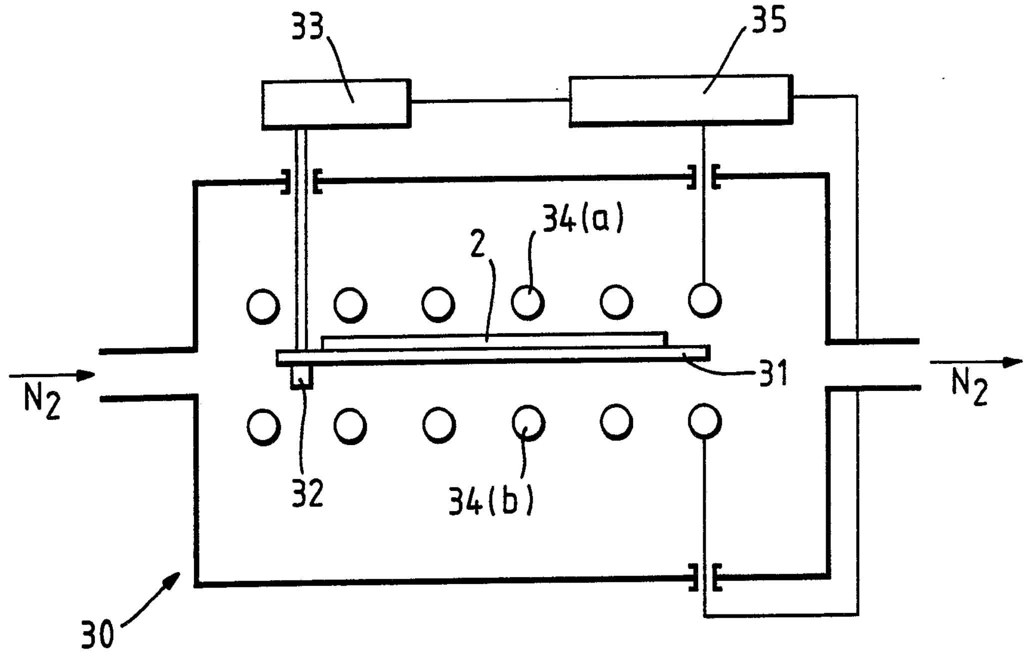


Fig. 2.

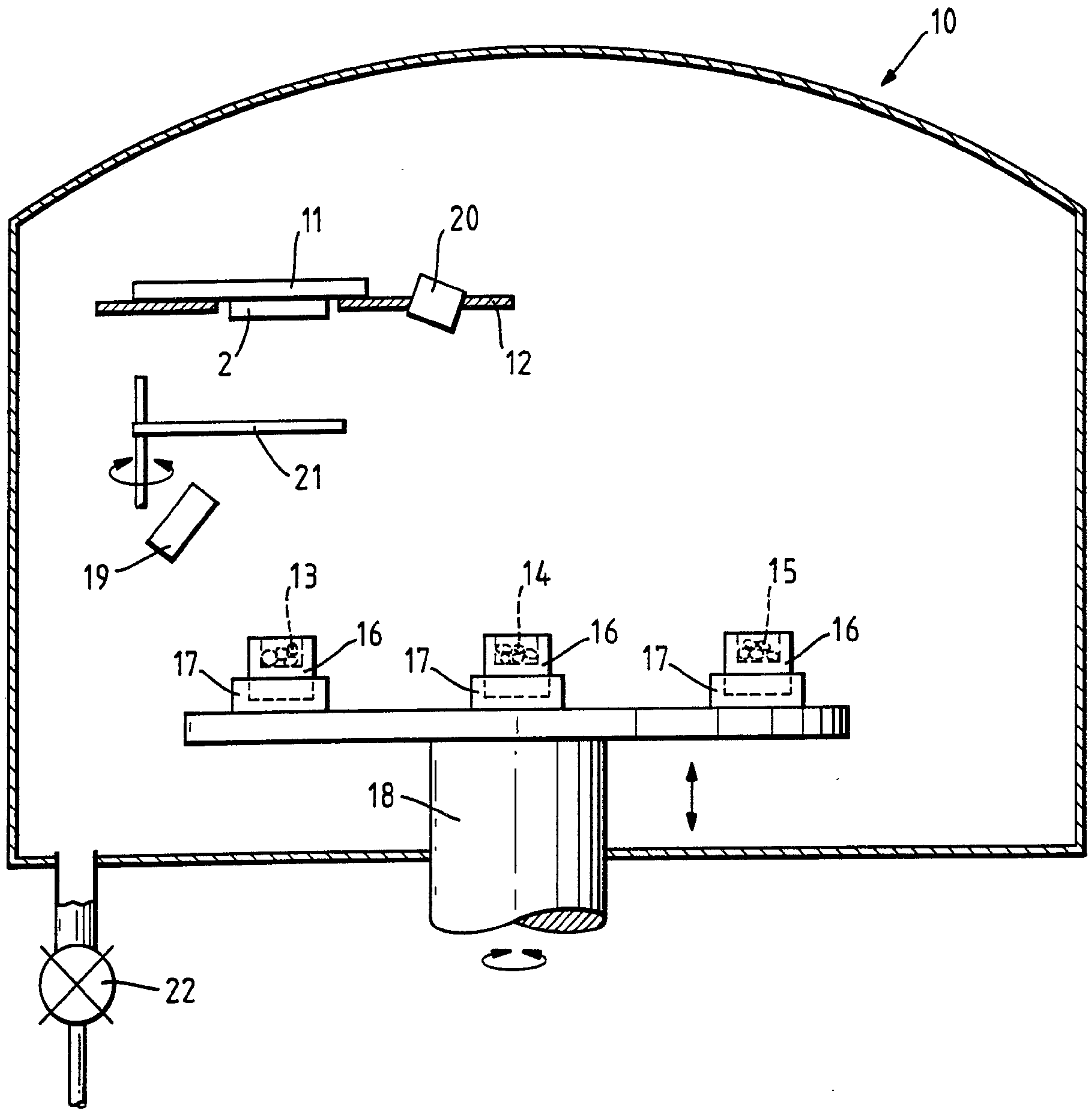
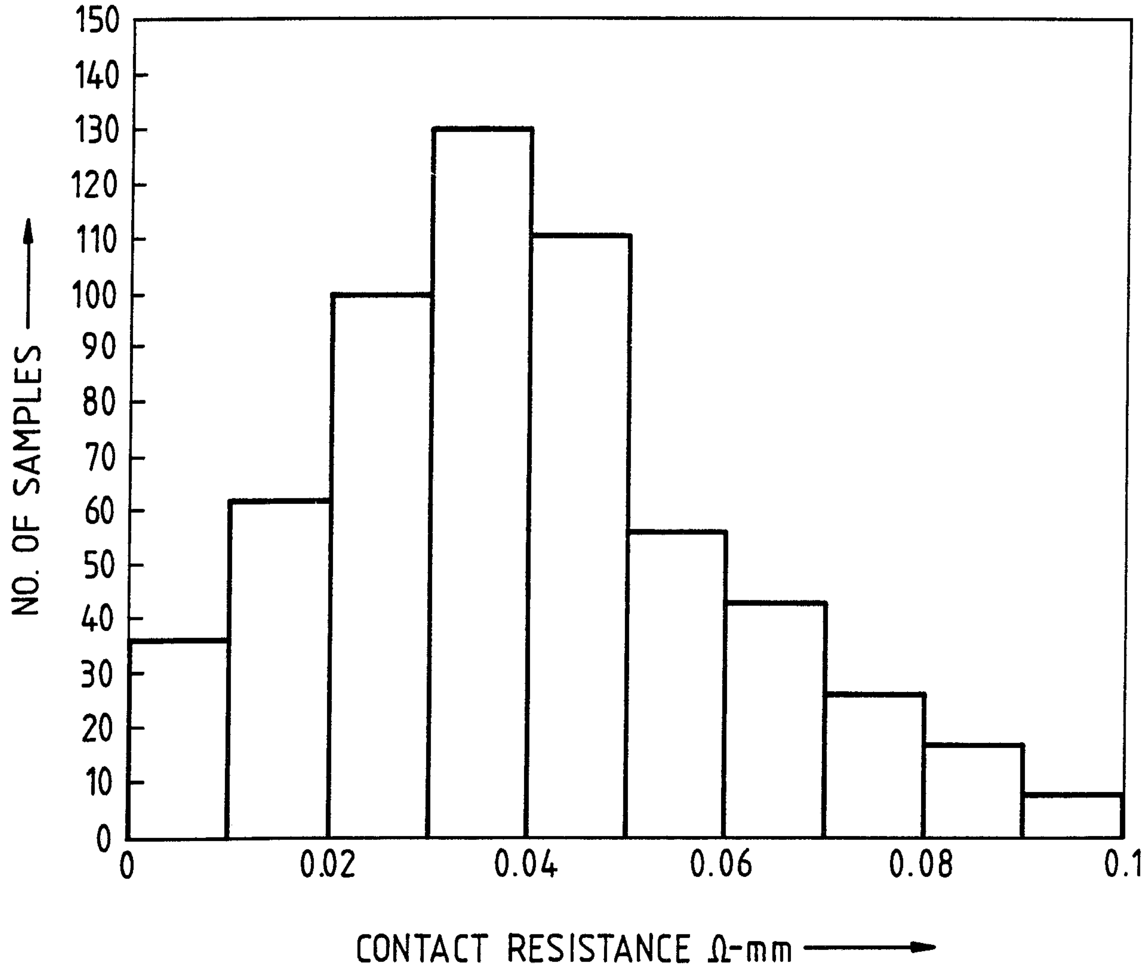


Fig. 4.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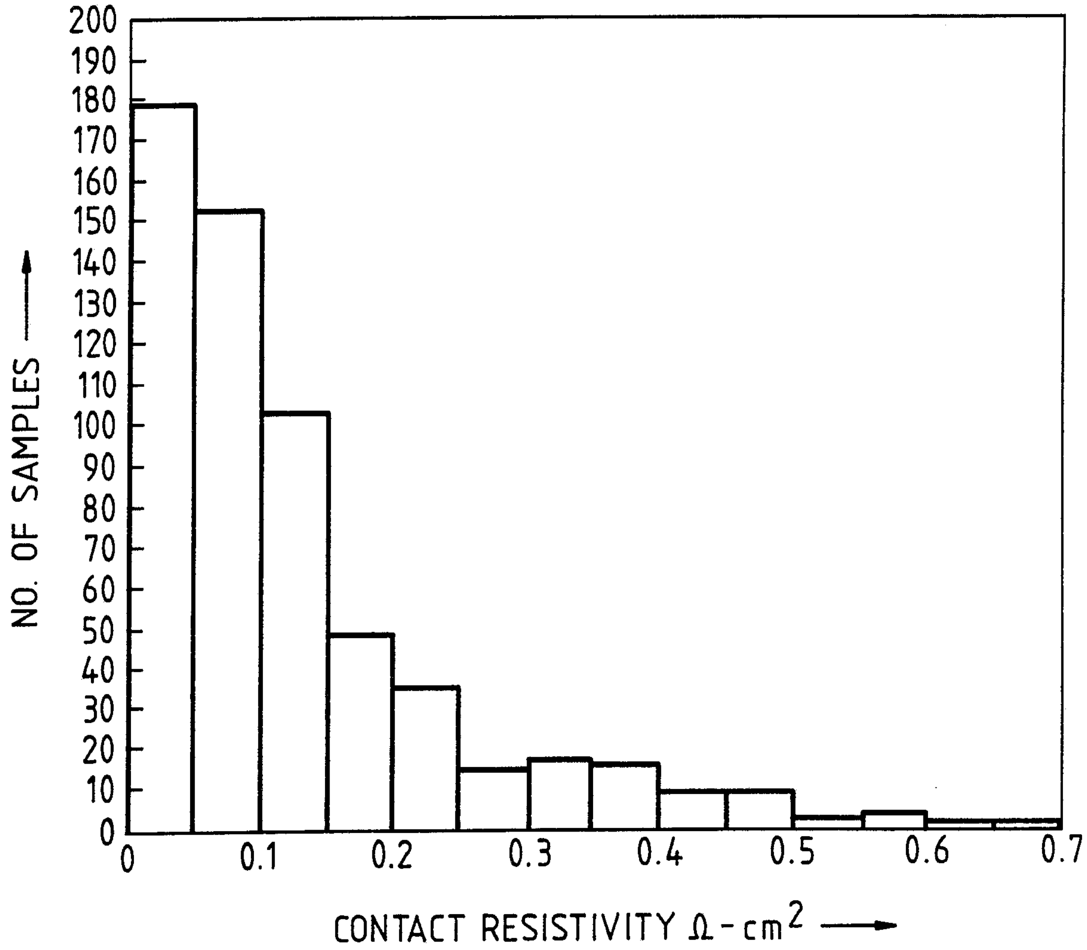
CONTACT RESISTANCE Ω-mm

Fig. 5.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0.3
0.4
0.5
0.6
0.7
CONTACT RESISTIVITY Ω - cm²

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 90/01382

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

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

IPC^5: H 01 L 29/40

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	H 01 L

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	IEEE Transactions on Electron Devices, vol. 36, no. 2, February 1989, IEEE,(New York, NY, US), H. Goronkin et al.: "Ohmic contact penetration and encroachment in GaAs/AlGaAs and GaAs FET's", pages 281-288, see pages 281-282, paragraph II.: "Sample Preparation" --	1,3
A	Thin Solid Films, vol. 176, no. 1, 1 September 1989, Elsevier Sequoia, (Lausanne, CH), R.K. Ball: "Improvements in the topography of AuGeNi-based ohmic contacts to n-GaAs", pages 55-68, see the whole article --	1

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
26th November 1990	18. 12. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. Peis — M. PEIS

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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	WO, A, 83/03713 (MOTOROLA, INC.) 27 October 1983 see the whole document	1

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9001382

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 11/12/90
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A- 8303713	27-10-83	EP-A- 0105324	18-04-84

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82