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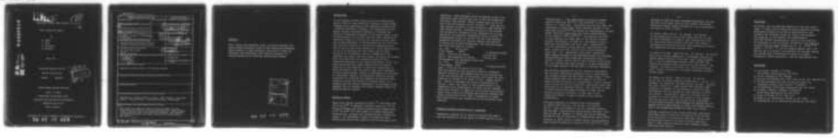

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INJECTION LIMITED GUNN DEVICES

Final Technical Report

by

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May 1978

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Thin, highly pure epitaxial layers of gallium arsenide were grown without conversion layer on semi-insulating substrates. Ohmic contacts to these epitaxial layers were studied and optimized. Both approaches were found prerequisite for reliable operation of injection limited Gunn devices.

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Abstract

Thin, highly pure epitaxial layers of gallium arsenide were grown without conversion layer on semi-insulating substrates. Ohmic contacts to these epitaxial layers were studied and optimized. Both approaches were found prerequisite for reliable operation of injection limited Gunn devices.

Introduction

In the proposal to ERO a device was to be studied which derives from the Gunn effect yet promises to yield higher frequencies by application of an additional terminal and a properly adjusted n.l product. The realization of this device requires excellent knowledge of thickness and electrical transport parameters of the active layer as well as close control of the ohmic contacts used. Commercially obtainable material is mostly not suitable for this work due to wide tolerances in specifications and the fact that the available material is too strongly compensated thus mobilities are lower than expected at a given concentration. It was to be expected from the outset that the work discussed in the proposal cannot be completed in the available six months. For this reason, two areas of research were initiated which are considered essential for a successful operation of the anticipated device. First, the vapor phase epitaxial growth system which has been in operation at the Institute of Industrial Electronics is being utilized to grow thin active GaAs layers according to close specification. Second, an understudy was initiated to understand, control, and eventually lower the contact resistance of electrodes and terminals on epitaxial GaAs. Progress on those two topics is discussed below. It is expected that the device configuration as discussed in the proposal will be available for further studies within the existing contract period.

Epitaxial Growth

Vapor phase epitaxy according to Effer (1) with $AsCl_3$ and six nines Ga (2) is employed. Epitaxial layers of 1 to 10 micron thickness with carrier concentrations ranging from $\leqslant 10^{14}$ to 2×10^{16} cm^{-3} were grown on Cr doped substrates. Unfortunately, problems were encountered with "conversion layers", i.e. presumably p-layers of relatively high conductivity between the substrate and the epi-layer. This conversion layer manifests itself in optical as well as in electrical tests and has been seen in many US laboratories working on GaAs devices. During a recent visit to the US one of the participants of this contract (3) found that no sure approach is known to avoid conversion layer buildup in vapor phase epitaxy. A possible solution of this problem was successfully attempted in this laboratory by in situ etching of the substrate immediately prior to growth (4). Thermodynamic control of the gas flow and vapor pressure parameters necessary for specular etching was difficult to obtain but has been accomplished. The following parameters are being used for etching:

H_2 - flow 267 ml /min
T (Ga source) 830°C T (substrate) 730°C
$AsCl_3$ - flow over Ga source 0.93 ml/ min
$AsCl_3$ - flow bypassing Ga source 1.85 ml/ min

The parameters for subsequent growth are:

H_2 - flow 267 ml/min.
T (Ga source) 830°C T (substrate) 730°C
$AsCl_3$ - flow over Ga source 2.77 ml/ min

With this method we find optically excellent interfaces. Reliable electrical measurements were not yet obtained due to the high resistivity of the samples. The reason for this restivity is thought to be either Cr back - doping during epi - growth or extremely low carrier concentration of the epi - layer. The latter is being investigated at lN_2 temperature in an experimental rig which was put together under this contract. In addition, we etch down the epitaxial layer using a specially designed ohmic contact geometry and measure resistivity of the layer in dependence of depth. This method allows easy recognition of any conversion layer existing.

Formation of Ohmic contacts on N - type GaAs

Preparatory research for an injection limited GaAs amplifier was carried out in the sphere of Ohmic contacts on epitaxially grown n - type GaAs layers the carrier concentration of which was $3x10^{15}cm^{-3}$ and $2x10^{16}cm^{-3}$. In both cases a Cr - doped semi - insulating substrate was used. The literature of recent years offers numerous methods of forming Ohmic contacts (5,6,7) but mostly for applications in field-effect transistor technology with doping concentrations in the range of 10^{16} to $5x10^{17}cm^{-3}$. The question was which of these methods were applicable to low carrier concentrations. Furthermore, we aimed at a reproducable single - mask thin film process. The usual test - configuration of three differently spaced bars was evaporated onto the GaAs - surface for the evaluation of contact resistance using lift - off - photoresist techniques. Immediately after sputter etching of the substrate surface the following contact materials were evaporated (evaporation rates in $nm.sec^{-1}$): Au(1), Cr(.5), Ni(.3) and a eutectic Au-Ge alloy (5). The contacts were then alloyed at various temperatures in the range between 375°C and 500°C in nitrogen atmosphere.

The essential component of all the contacts investigated was Ge, which substitutes preferably into Ga sites during the alloying process and thus forms a highly doped n^+ interlayer between n-GaAs and the metal-contact. In order to reduce the melting point, it is convenient to use a eutectic alloy of AuGe (27 at.% Ge, $T_s=356^oC$). Additional metals were evaporated as an interlayer between GaAs and AuGe in order to enable wetting and improve adhesion of AuGe, and to prevent balling up. Moreover, in some cases Au was evaporated finally in order to obtain a high surface-conductivity.

Following sequences of materials were investigated:

a) (GaAs-) AuGe (124 nm) - Ni (40 nm) - Au (100 nm)

The Ni - layer was thought to act as a diffusion barrier for the gold - plating which should prevent the AuGe - melt from balling up. However, it turned out that Au diffuses through Ni even at relatively low temperatures (above 400°C). Alloying at 380°C yielded a smooth surface but unacceptably high contact-resistance of 13Ω.mm to the $3x10^{15}$ cm^{-3} GaAs.

Alloying at 400°C and more increased successively the number and size of metal balls on the surface. The contact resistance remains almost unchanged at 2 to 4 Ω.mm within the range of 400°C to 500°C.

b) (GaAs-) AuGe (125 nm) - Cr (40 nm) - Au (100 nm)
As the evaporation of Cr is much easier than Ni we used the same arrangement as before, just substituting Ni by Cr. The results were optically the same. The contact-resistance had qualitatively the same dependance on alloying temperature but the fourfold value.

c) (GaAs-) Cr(2 nm) - AuGe (107 nm) - Ni (33 nm) - Au (45 nm)
Here a thin, highly adhesive Cr - interlayer aimes at reducing surface tension of the AuGe - melt. After alloying for 1 min at temperatures between 375°C and 460°C the surface was smoother than in case a) but the contact - resistance was worse by a factor of 2. Due to the thinner gold - plate, the surface - resistance increased to about 5Ω per square.

d) (GaAs-) Ni (30 nm) - AuGe (110 nm) - Ni (30 nm)
As Au tends to diffuse rapidly through any Cr - or Ni - interlayer, an experiment was made without the gold - plating, but with a thick Ni - layer between GaAs and AuGe. When alloying, no tendency of the material to ball up could be observed over the temperature range applied. At 430°C the contact - resistance of 3Ω.mm was a minimum but increased up to the fourfold after ageing at room temperature for one week. Thus this method can be recommended if very smooth surfaces (sharp bounds) are desired but requires an extra photo-process to cover the alloyed contact with a well-conducting protective layer (e.g. Cr-Au).

Although evaporation of Ni is very difficult, additional experiments will be made with Ni-AuGe-Ni-Au and Cr-AuGe-Cr-Au structures. In conclusion, AuGe-GaAs contacts with Ni-interlayers and/or a Ni surface plating generally offer a lower contact-resistance and a smoother surface than those made with Cr.

The Device

We believe that the physical chemistry to grow the active layer is under control expect for narrow control of doping. Preliminary studies of the device characteristics and geometry were conducted along the lines of the proposal. Our plans are to use material with approximately $2 \times 10^{15} cm^{-3}$ carrier concentration, with as high a mobility as obtainable in our VPE growth. According to the generally accpted rules for domain generation, $NL \approx 10^{13} cm^{-2}$ (8) and $Nd \approx 10^{12} cm^{-2}$ (9), we will employ samples with $L \approx 50$ microns and $d \approx 5$ microns. The geometry for the gate contact has already been investigated but mainly for domain triggering. Domain suppression will be investigated next.

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