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GaAs Strip Detectors: the Australian Production Program

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Introduction

High Energy Physics is often regarded by the uninitiated as a fairly esoteric subject having little practical significance. The reality is that the governments of Europe, America and Japan invest billions of dollars into High Energy Physics, not because of their unwavering support for the quest for knowledge, but because of the development of new technologies and spawning of new industries which inevitably occurs when supporting major scientific ventures. In a similar way to the NATO and European space programs, High Energy Physics projects - such as those being developed at CERN - have mobilised large numbers of scientists at the cutting edge of new technologies. Industry has also been mobilised into supporting such projects; employment has been created, and spin off technologies are being actively investigated. The practical benefits of such large investments are being fully realised.

In monetary terms the Australian contribution to High Energy Physics has been small compared to that of other nations, yet even here there is a realisation that Australia should endeavour to master and take advantage of the technologies being developed. In line with this practical view the Australian High Energy Physics consortium (composed of The University of Melbourne, the University of Sydney and ANSTO) has been taking a small but active role in the development of the radiation detector technologies which are necessary for collider experiments at CERN. New radiation resistant detectors based on semi-insulating (SI) GaAs have been developed by R&D groups at CERN as a direct response to the needs of the large hadron collider (LHC) experiment. To date the small size of the Australian effort (which is commensurate with funding levels) has meant that it has been limited to a peripheral position which has excluded it from developing many aspects of this technology, and has certainly limited the group's ability to contribute and take advantage of related advances. Recently ,however, the Australian consortium has been investigating the possibility of producing a large area wheel of SI GaAs detectors for the ATLAS detector array. To help assess the extent of Australia's role in this venture a few SI GaAs microstrip detectors are to be manufactured under contract by the CSIRO division of Radiophysics GaAs IC Prototyping Facility.

The production of SI GaAs microstrip detectors even in low volume represents a significant upgrading of the Australian research effort into these devices, and for this talk the planned production of the devices is discussed. First of all the reasons for producing the detectors here in Australia are examined, then some basic characteristics of the material are considered, and then finally details are provided of the design used for the manufacture of the devices.

Reasons

1) Experience will be gained in the fabrication of the devices. Once experience has been gained in the procedures and limitations of fabrication the Australian consortium will be on a better footing to decide future directions for the building of the GaAs wheel.

2) Devices will be available for testing and experimentation. Sydney University will have access to strip detectors for the detection of cosmic rays and minimum ionising particles. The University of Melbourne will be able to introduce students to the technology of GaAs strip detectors and carry out characterisation of the detectors via techniques already developed there for silicon devices. For ANSTO experience will be gained in semiconductor measurement techniques as applied to strip detectors. This will help provide expertise for higher level testing of strip detectors actually made for the GaAs wheel. Beam testing of GaAs strip detectors can proceed at CERN without relying on others to graciously supply the detectors.

3) This preliminary run of GaAs devices will provide the Australian consortium and the IC prototyping facility of CSIRO Radiophysics with the appropriate knowledge and expertise to upgrade to produce devices for the detector wheel at CERN, should that be demonstrated to be a viable direction.

4) This exercise will give the Australian consortium a greater chance to provide practical input into, and perhaps improve, the design of GaAs microstrip detectors, and any future generations of GaAs detectors. It will do this by providing a technology base here in Australia which will give the consortium the flexibility to experiment with the design and fabrication of working devices and to conduct further testing of those devices. Improvements in design can then be physically demonstrated.

5) Such an exercise, even if only moderately successful, would enhance the profile of the Australian High Energy Physics consortium, within Australia, at CERN, and within the High Energy Physics community in general. It should also open new avenues for publication. To be able to point to a GaAs microstrip with the built in Australia logo could be quite advantageous in terms of obtaining funding for future activities of the consortium.

6) The consortium may also profit from the possibility of applying some of the constructed devices in spin off applications, such as a position sensitive X-ray detection for synchrotron X-ray diffraction experiments.

Material Considerations

Materials and semiconductor scientists have been involved at a rather late stage in the development of semiconductor technology for experiments at CERN, so that in some of the literature there is a strong propensity to regard SI GaAs in terms of experience gained from silicon. In terms of efficiency for the detection of radiation, material of low carrier concentration, and a very much lower concentration of deep level recombination centres (traps), may be regarded as being highly desirable. A traditional measure of how "good" a material will be for radiation detection is given by the $\mu\tau$ (carrier mobility x carrier lifetime) product, a higher $\mu\tau$ product indicating a better detector material [1,2]. This measure has been adopted since improvement in the quality of a semiconductor material is ultimately required in order to improve its charge collection efficiency (η). In a simplified model (not strictly applicable to SI GaAs, but useful here for demonstration purposes) the $\mu\tau$ product is related to η through the Hecht equation [3], given here in its simplest form for the case of a one carrier system

$$\eta = \mu\tau\varepsilon/x\,(1 - e^{-x/\mu\tau\varepsilon}) \qquad (1)$$

where ε is the electric field and x is the device thickness. η, itself, is defined as the ratio of the charge created in the device by a photon or particle of radiation, to the charge collected. Also related to η through the Hecht equation is the mean free path of the carriers (λ) given by

$$\lambda = \mu\tau\varepsilon \qquad (2)$$

this value has become widely used for the assessment of radiation detector devices, as opposed to device materials (see for example [4]).

From the Hecht equation the $\mu\tau$ product will be high when the carrier concentration is low and when there is a relative freedom from deep level recombination centres. Deep level recombination centres act to lower τ. Because silicon can be processed to extremely high purity, higher resistivity material often translates to a high $\mu\tau$ value since trap concentrations are generally insignificant below resistivities of about 10 kΩ·cm. The high resistivity of SI GaAs (about 10^7 Ω·cm) has therefore often been misinterpreted as being a positive characteristic of this material. Unfortunately the semi-insulating behaviour of SI GaAs is due to a large concentration of deep level traps which over compensate shallow donor and acceptor levels within the material. These deep levels act as carrier liftime "killers" and therefore this material has a comparatively low $\mu\tau$ product of approximately 1×10^{-5} cm^2 V^{-1}. High quality liquid phase epitaxial (LPE) GaAs on the other hand has a significantly lower resistivity than SI GaAs however this material can be grown free of detectable concentrations of deep level traps [5] and can therefore have a relatively high $\mu\tau$ product. Values as high as 0.25 cm^2 V^{-1} have been measured [6] and LPE GaAs is therefore a better quality material for radiation detection, as further evidenced by several recent publications comparing the charge collection efficiency of LPE and SI GaAs [7,8]. The main advantage of SI GaAs is that it is commercially produced in bulk quantities whereas high purity LPE material is not. Good charge collection for SI GaAs is obtained by increasing the electric field across the device and by using thin device cross-sections.

Similarly, for silicon detectors irradiated by a high neutron fluence (ie. at the levels expected for the LHC) the decrease in free carrier concentration is not a positive attribute. The decrease in shallow level carrier concentration is commensurate with an increase in deep level recombination centres due to neutron damage [9] so that again there is an overall lowering of the $\mu\tau$ product.

Design

The present design is based on a 2" wafer mask set supplied by Glasgow University. The mask set determines the processing steps and the physical layout of the devices. Although designs based on larger wafers are envisaged for the final ATLAS design, the Glasgow mask set, which has been well tested, is being used as a benchmark against which to compare the Australian devices.

At least two sets of detectors will be produced using the standard Glasgow production recipe, and it is believed that if all goes well the SI GaAs used by the Australian consortium (supplied by Frieburger rather than EEV) may well lead to superior devices compared to those produced at Glasgow. Using the same mask set other devices will be prepared with the aim of improving upon the Glasgow design. Two main avenues of investigation are envisaged at this time:, first of all the back contact of the microstrip devices has recently been shown to be critical in controlling the breakdown voltage of the devices [10]. Different back contact metallisation will be investigated to increase the breakdown threshold. Secondly the passivation of SI GaAs microstrip devices has not been well developed, SiN is presently used to encapsulate the devices but is a poor electrical passivant for GaAs. It is believed however that GaN, a wide bandgap insulator which may be produced by processing the GaAs surface may offer a more effective alternative. Past papers have shown that GaN produced on GaAs by treating the surface with a nitrogen plasma can reduce currents so that greater voltages can be applied to devices [11].

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