AU9817103

Single Ion Transient-IBIC Analyses of Semiconductor Devices using a Cryogenic Temperature Stage

J.S.Laird, R.Bardos, C.Jagadish* and G.J.F.Legge

Micro Analytical Research Centre (MARC),
School of Physics, University of Melbourne, Australia.

* Electronic Materials Engineering (EME),
School of Physics, Australian National University,
Canberra, Australia

Abstract:

We present here a paper describing the new Transient - IBIC data acquisition and analysis system at MARC. A discussion on the need for single ion control and temperature control is also given. The new cryostatic temperature control stage is introduced. Data is presented demonstrating the potential improvements in spatial resolution in materials of long lifetime by mapping on timing windows around the prompt charge component in the charge transient.

Introduction:

Ions traversing a semiconductor material give rise to an e-h plasma whose subsequent interaction with the local crystal structure and collection via neighboring space-charge regions is the basis of the Ion Beam Induced Charge (IBIC). Transient current techniques using heavy MeV ions have been used for the simulation of single event process (SEU). IBIC has also been applied to the SEU problem with its main advantage over the EBIC and OBIC technique being an energy selectable end of range to probe structure at a particular depth without removal of passivation layers. For a more complete characterization of a device though, the temporal dependence of the collection process contains more information than the integrated charge pulse height alone, as typically used in IBIC analysis. Acquisition of the spatio-temporal response of the device leads to investigation of time dependent device phenomena such as those associated with trapping processes and lifetimes.

Purpose of Single Ion Control

Single ion control in Transient-IBIC is necessary due to the low transfer rates found with transient recorders and Digital Storage Oscilloscopes (DSO's). The damage induced from ions striking the device during the transient capture and transfer process degrades the device. Ideally the beam current is matched to the transient collection rate (typically less than 20Hz). Maintaining such current is difficult since beam bunching and timing spread leads to frequency components larger than the steady state required. Minimal beam is necessary for non-destructive analysis. The second point in favor of single ion control is that of controlling the timing of the ion injection process. The aspect of timing control needs careful consideration as the dynamic range in transient widths can be from fractions of μsec's to many *m*sec's in the case of Scanning Ion-DLTS. At long transient widths pulse pileup in the current transients can introduce a significant source of error reducing the available timing window. Using a single ion system enables wider windows in transient widths for a given beam current.

Transient-IBIC System Design

The single ion system employs rapid electrostatic beam switching after the event detection has occurred. For Transient-IBIC the recorded signal is used as the event trigger for beam pulsing. Figure 1 below schematically illustrates the single ion beam line used for Transient-IBIC analysis.

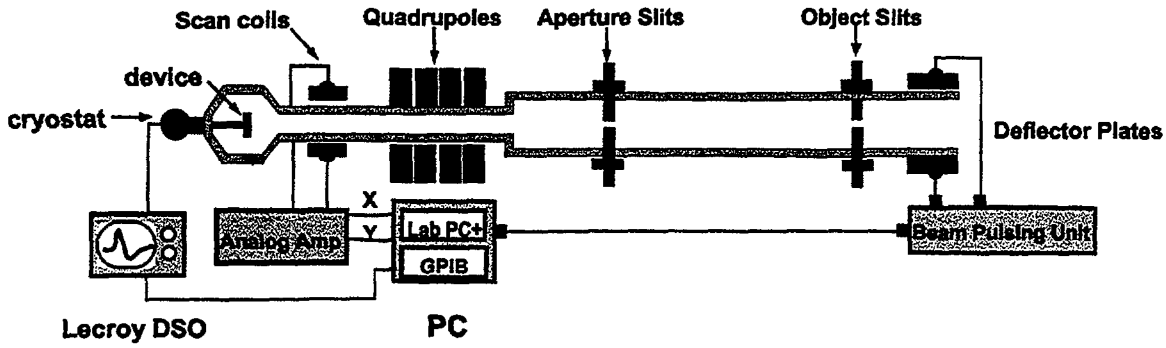


Figure 1: A schematic of the complete Transient-IBIC analysis system.

The diagrams consists of, going from right to left, a beam pulsing unit for fast timed deflection; the microprobe object and aperture slits determining the 1st order beam spot size, lenses for beam focusing, ferrite core coils for beam scanning with a transconductance amplifier supplied with scan signals from a PC Lab PC+. The DUT is mounted on an X-Y-Z cryogenic stage with an Amptek A250 charge preamplifier for charge transient collection.

Scanning System and Beam Pulsing

The scanning system comprises a PC running Labview 4.0 equipped with a National Instruments LabPC+ and GPIB-TNT+ card for both scan generation and lab control. A GPIB-TNT+ card is used for instrumental control of a 300MHz Lecroy 9361 DSO, Keithley 487 bias supply and Conductus LTC-10 temperature controller. Scan generation is achieved by the dual 16-bit DAC's onboard the Lab PC+ card driving a transconductance amplifier through orthogonal magnetic dipole coils.

The scanning software allows programmed shape scanning with adjustable pixel spacing accommodates. multiple ions per pixel. Scan rastering is based upon the hardware trigger supplied by the Amptek A250. Upon receiving an event tag, the beam pulsing system blanks the beam, downloads the transient as captured on the DSO and repositions the beam to the next scan position. Having repositioned the beam, the BPU receives an ON condition, and the process is repeated over the array. For any given array, a Keithley 487 picoammeter Voltage source both monitors the device leakage and sets the operating bias. Likewise, the temperature for the array can also be set and monitored during an individual pass, although in practice the reduction in the collection rate due to extra instrument calls means the internal scan loop is designed to make no more calls than necessary. Temperature and leakage readings are acquired at the completion of a given scan. The software is written in a modular fashion to accommodate various experimental configurations with the optimal collection rate being 18Hz.

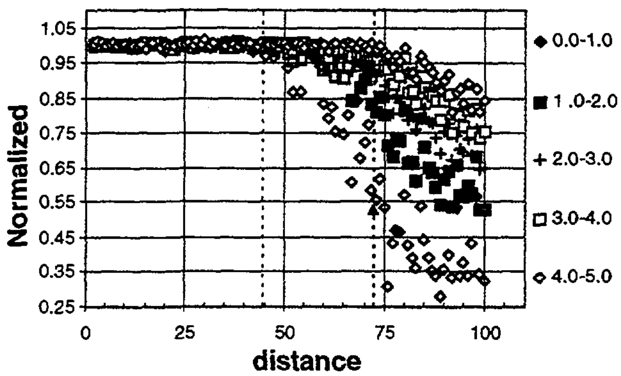
Cryogenic Temperature Control

A CTI Cryogenics cryodyne liquid He cryostat and compressor with a Conductus LTC-10 Temperature Controller are used for device heating and cooling between 30-320K in the microprobe chamber. The LTC-10 controller incorporates an automated PID feedback system using 2 Si - diode temperature sensors and a 100Ω heater as shown in figure 2. The controller is able to maintain temperature stability of 0.005K over a broad range of thermal loads. Since typical vacuums in operation are of the order of 10^{-6}-10^{-7} torr convective loss is negligible. Radiative losses requires IR shielding. A polished aluminium shroud sitting at 77K acts as a radiative shield in the lower section of the cryostat (1st and 2nd stages). From the base of the balanced bellows section and into the target chamber, thin aluminized mila foil covers the copper conduction path providing radiative shielding. The entire cryostatic and interface to the target chamber are mounted on a x-y-z stage for external alignment

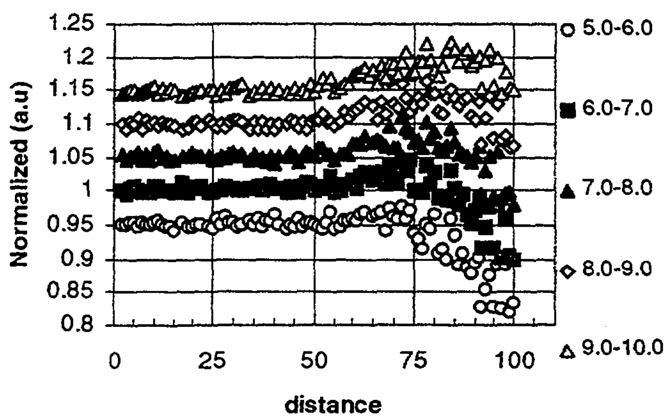
Large vibrations from the refrigerator and liquid He compressor require vibrational isolation for the spatial resolution not to be adversely affected. We achieve this using a balanced bellows in the y-direction for decoupling vibrations along the housing. A Bruel & Kjaar piezoelectric accelerometer and charge sensitive preamplifier connected to the DSO are used to examine the vibrational spectrum using Fourier decomposition. Both the damping factors and directionnal components can be analyzed. Both STIM and vibrational monitoring point to near complete damping of the vibration along the vacuum housing to within a μm. Vibrations on the thermal pathway are more difficult to remove primarily because mechanical interference reduces both conductivity to the sample and introduces thermal leakage. Design is therefore crucial and we have taken the approach of designing a rigid vertical pathway connected to the target holder via a series of copper braid wound into springs.

Data and Results:

Shown below are the extracted line profiles across the edge of a Au-Si junction collected at 52K. The profile is produced by integrating the transient in a given timing window and normalizing to the complete charge transient. The images are sensitive to pulse shape and indicate the dependence on diffusion on carrier velocity and distance of injection point to the Au-Si pad. The Au-Si pad is seen to sharpen in response to forming shorter timing windows. Diffusion from outside the pad can be removed as shown in fig 2(a). In figure 2(b) the image is most comprised on diffusing charge over longer time intervals.



(a)



(b)

The analysis of the profile has involved electrical characterization over the temperature range of 25-300K using a developed C-V and I-V variable temperature stage incorporating a liquid helium cryostat. Bandwidth limitations have been theoretically calculated for a junction including regions of partial depletion and compared to the risetime measurement of 60ns.