MATERIAL CHARACTERIZATION USING ION BEAMS pdf

1: Material Characterization Using Ion Beams

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Ionization is a step-by-step process from collisions of the accelerated electrons with the desired vapor atoms. The gyrofrequency of an electron is calculated to be 1. To do this, a high voltage is between the hexapoles applied to pull out the ions from the magnetic field. It is very important that the ion source used is optimal for the experiment being carried out. To perform an experiment in a practical amount of time, the ions provided from the accelerator complex should have the correct desired energy. In this set up, the angle is calculated as to allow the incident ions to scatter off of the sample so that there is no contact made with the detector. The physical basis that has given the method its name stems from the elastic scattering of incident ions on a sample surface and detecting the recoiling sample atoms while the incident ions backscatter at such an angle, that they do not reach the detector; this is typically in reflection geometry, [1] illustrated in figure shown: Another method for preventing incident ions from making contact with the detector is to use an absorber foil. During analysis of the elastically recoiled particles, an absorber foil with selected specific thickness can be used to "stop" the heavy recoil and beam ions from reaching the detector; reducing the background noise. Incorporating an absorber into the experimental set up can be the most difficult to achieve. The stopping of the beam using either direct or scattered methods can only be accomplished without also stopping the light impurity atoms, if it is heavier beam ions than the impurity atoms being analyzed. In thicker samples there is some degradation of mass resolution and slight loss of sensitivity. The detector solid angle has to be closed, but the thick sample can take more current without heating, which decreases sample degradation. The beam ions are scattered at an angle that does not permit them to reach the detector. The sample ions pass through an entrance window of the detector, and depending on the type of detector used, the signal is converted into a spectrum. Silicon Diode Detector[edit] In elastic recoil detection analysis, a silicon diode is the most common detector. For example, the energy resolution decreases significantly with a Si detector when detecting heavy recoiled ions. There is also a possibility of damage to the detector by radiation exposure. These detectors have a short functional lifetime 5â€”10 years when doing heavy ion analysis. Therefore, the simple range foil ERD has two major disadvantages: This method does not present the same issues, as those for the silicon detector. However, the throughput of TOF detectors is limited; the detection is performed in a serial fashion one ion in the detector at a time. The longer the TOF for ions, the better the time resolution equivalent to energy resolution will be. Detectors in modern time-of-flight instruments have improved sensitivity, temporal and spatial resolution, and lifetimes. Ionization Detector[edit] A third type of detector is the gas ionization detector. The gas ionization detectors have some advantages over silicon detectors, for example, they are completely impervious to beam damage, since the gas can be replenished continuously. Figure 7 shows the Gas Ionization chamber with Isobutane as the detector gas. Gas Ionization Chamber showing the positive charges migrating toward the cathode and the negatively charged ions migrating toward the sub divided anode through a Frisch Grid. There are various designs of ionization detectors but a general schematic of the detector consists of a transversal field ionization chamber with a Frisch grid positioned between anode and cathode electrodes. The anode is subdivided into two plates separated by a specific distance. A polypropylene foil was used as the entrance window. It has to be noted that the foil thickness homogeneity is of more importance for the detector energy resolution than the absolute thickness. The cathode electrode is divided in two insulated halves, thus information of particle entrance position is derived from charges induced at the right and left halves. Using I ion beam, a profile of various elements can be obtained and the amount of contamination can be determined. High levels of carbon contamination could be associated with beam excursions on the support, such as a graphite support. This could be corrected by using a different support material. Using a Mo support, the carbon content could be reduced from at. With ERDA and heavy ion projectiles, valuable information can be obtained on the light element content of thin foils even if only the energy of the recoils is measured. The copper coating and the glass substrate was also identified. Using a solid angle of 7. It is important when designing an experiment to always consider the geometry of the system as to achieve recoil detection. In this geometry and with Cu being the heaviest component of the sample, according to eq. This type of film showed superconductivity at one of the highest-temperatures for oxide superconductors. These elemental constitutes of the polymer film Bi, K, Mg, O, along with carbon contamination were detected using an ionization chamber. Other than Potassium, the lighter elements are clearly separated in the matrix. Some films showed a 1: This is a powerful tool for materials characterization. Being able to quantify elemental concentration in sub-surface layers can provide a great deal of information pertaining to chemical properties. To Understand Forward recoil spectrometry we should know the physics involved in Elastic and Inelastic collisions. In Elastic collision only Kinetic Energy is conserved in the scattering process and there is no role of particle internal energy. Where as in case of Inelastic collision both kinetic energy and internal energy are participated in the scattering process. Fundamentals of Recoil Back Scattering Spectrometry[edit] The Fundamental aspects in dealing with recoil spectroscopy involves electron back scattering process of matter such as thin films and solid materials. Energy loss of particles in target materials is evaluated by assuming that the target sample is laterally uniform and constituted by a mono isotopic element. This allows a simple relationship between that of penetration depth profile and elastic scattering yield [33] Main assumptions in physical concepts of Back scattering spectrometry[edit] Elastic collision between two bodies is the energy transfer from a projectile to a target molecule. This process depends on the concept of kinematics and mass perceptibility. Probability of occurrence of collision provides information about scattering cross section. Average loss of energy of an atom moving through a dense medium gives idea on stopping cross section and capability of depth perception. Statistical fluctuations caused by the energy loss of an atom while moving through a dense medium. This process leads to the concept of energy straggling and a limitation to the ultimate depth and mass resolution in back scattering spectroscopy. Depth profile and Resolution analysis[edit] A key parameter that characterizes recoil spectrometry is the depth resolution. This parameter is defined as the ability of an analytical technique to measure a variation in atomic distribution as a function of depth in a sample layer. In terms of low energy forward recoil spectrometry, hydrogen and deuterium depth profiling can be expressed in a mathematical notation. Let us consider an Incoming and outgoing ion beams that are calculated as a function of collisional depth, by considering two trajectories are in a plane perpendicular to target surface, and incoming and outgoing paths are the shortest possible ones for a given collision depth and given scattering and recoil angles. Detection is possible at one of these angles as such that the particle crosses the target surface. Paths of particles are related to collisional depth x, measured along a normal to the surface.

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2: Vion Plasma Focused Ion Beam for Materials Science | Thermo Fisher Scientific

Get this from a library! Material Characterization Using Ion Beams. [J P Thomas; A Cachard] -- The extensive use of low-energy accelerators in non-nuclear physics has now reached the stage where these activities are recognized as a natural field of investigation.

Department of Materials Science and Engineering The Materials Characterization Facility is open to all research groups within the university for structural and microstructural characterization using electron, x-ray, and scanning probe methods. The facility staff provide assistance and training in all of these techniques to enable research groups to achieve their research objectives. Additionally, the suite houses a significant fraction of the departmental computational facilities. Any published research using MCF instrumentation should include the following acknowledgement statement: The Carnegie Mellon University CMU MCF facility is a multiuser materials characterization facility for the structural and chemical characterization of materials using methods including electron microscopy, scanning probe microscopy and x-ray diffraction. Where is MCF located? What is available at MCF? This website features specific information on individual instruments. In general, MCF houses three transmission electron microscopes, four field emission scanning electron microscopes, two focused ion beam systems, multiple x-ray diffractometers and multiple scanning probe microscopes. MCF also houses many instruments for the preparation of specimens for characterization, including saws, polishing wheels, ion polishing systems, plasma cleaning devices, sputter coaters, etc. I would like to access MCF; what do I do? We recommend the following course of action: First, please determine exactly the nature of the analysis you require and anticipate the necessary steps for preparing your specific samples for that analysis. When trying to determine what analysis you want to pursue, consider the necessary resolution, sensitivity, spatial area, the need for specific location analysis, etc. Based on these considerations, attempt to anticipate what specific instrument you will want to use. Contact by email the appropriate MCF staff contact for the instrument you have identified: Betsy Clarke eac1 andrew. When you email MCF staff, include your answers to from above. Also mention any prior experience you may have had. If you have no prior experience, try to sit behind a colleague and watch them use the instrument for a session or two. Instrument handbooks are available on each Web page. Please read the instrument handbook before you come to training. Bring a printed copy with you to make notes on during your training sessions. Depending on the instrument, proficiency could be attained within training sessions. Proficiency is determined by MCF staff. After-hours facility and instrument access is allowed on individual case-by-case basis. How much will it cost? Instrument rates are provided at the following links:

3: Semiconductor Characterization by Scanning Ion Beam Induced Charge (IBIC) Microscopy

A summer school on "Material Characterization Using Ion Beams" has resulted from these developments and the realization that the use of ion beams is not restricted to accelerators but covers a wide energy range in the developing technology.

 Abstract The ion beam induced charge IBIC technique is a scanning microscopy technique which uses finely focused MeV ion beams as probes to measure and image the transport properties of semiconductor materials and devices. Its success stems from the combination of three main factors: The second reason stems from the peculiarity of MeV ion interaction with matter, due to the ability to penetrate tens of micrometers with reduced scattering and to excite a high number of free carriers to produce a measurable charge pulse from each incident ion. Last, but not least, is the availability of a robust theoretical model able to extract from the measurements all the parameters for an exhaustive characterization of the semiconductor. This paper is focused on these two latter issues, which are examined by reviewing the current status of IBIC by a comprehensive survey of the theoretical model and remarkable examples of IBIC applications and of ancillary techniques to the study of advanced semiconductor materials and devices. Introduction A charged particle with energy higher than 10 eV i. If the primary charged particles are electrons, a large fraction of their energy can be lost in a single interaction, and their trajectories within the material are very tortuous because their mass is equal to that of the orbital electrons with which they are interacting. Also in the case of energetic MeV ions, most of their energy is lost in collisions with the atomic electrons; the interactions with the atomic nuclei occur much more rarely. Therefore, the ion undergoes a huge number of interactions and gradually loses its kinetic energy: The range of MeV light ions in matter is mainly determined by the electron stopping power i. Monte Carlo simulators of ion energy loss such as stopping range in matter SRIM [4] are readily available for estimating the depthwise energy-loss profile of an MeV ion. The interaction of the primary ions with the atoms in the material induces the release of energetic electrons delta rays with eV to keV energy, that subsequently lose their energy through the interaction with the orbital atomic electrons. In a semiconductor, the overall significant effect is the production of many electron-hole pairs EHPs. The net result of such a process is the generation of a plasma volume along the ion track, with a submicrometer radial extension and a characteristic cone shape due to the fact that, as the ion slows down, delta rays become less energetic, and the generation volume collapses at the end of ion range [5 , 6]. According to the semiempirical model of Klein [7], the amount of energy available to create EHPs is largely independent of both the energy and type of the ionizing radiation, and the average energy required to produce one electron-hole pair is of the order of few eV 3. In summary, the interaction of a single MeV ion with a semiconductor material generates a high-density volume of free carriers along the ion trajectory, which is nearly a straight line, with a typical energy-loss profile, known as Bragg curve, peaked at the end of the ion range. Due to the high number of EHPs created, a measurable charge pulse can be extracted from each ion strike and processed by an external circuit, which allows the generation of a histogram of pulse heights the pulse height spectrum. In case of monoenergetic radiation, the counts are distributed around an average pulse height which is called the peak centroid. The position of the peak centroid is proportional to the measured charge at the electrode; the ratio of such a charge and the charge generated by ionization is the charge collection efficiency CCE , which is the most important parameter used to characterize electronic devices, in particular semiconductor detectors [2]. The electronic response of a semiconductor to the irradiation of a single MeV ion is a function of the generation profile and of the mechanism of charge-pulse formation: As a consequence, if a monochromatic ion probe is provided by an MeV ion accelerator, the measurement of charge pulses provides valuable information on the electronic characteristics of semiconductors. Moreover, these informations are greatly enhanced if the MeV ion beams are focused and raster scanned over the surface of the specimen. In fact, the knowledge of the ion strike position combined with the almost straight ion trajectory, the large analytical depth, which can be modulated as function of ion energy and mass and the submicrometer radial extent of the charge carrier generation volume, allows the electronic features of semiconductors to be spatially resolved at the micrometer level. These are, in summary, the main features of the ion beam induced charge IBIC microscopy, which has found widespread applications since the early s [8] for the characterization of electronic materials and devices, with considerable research activities carried out in many laboratories, as testified by the numerous papers published in journals as Nuclear Instruments and Methods in Physics Research and dedicated sessions in international conferences as the International Conference on Nuclear Microprobe Technology and Applications [9]. In the last twenty years, some review papers [10 , 11] and textbooks [3] have been published on the experimental setups, measurement protocols, and applications of IBIC to image and analyse the electronic properties of microelectronic devices, dislocations, semiconductor radiation detectors, semi-insulating materials, high power transistors, charge-coupled arrays, solar cells, and light-emitting diodes, in conjunction with single event upset imaging. This paper focuses on some theoretical aspects, which are needful to provide solid interpretations of IBIC experiments and remarkable examples of electronic characterization of important semiconductor materials. Charge Induction and Signal Formation As already stated in the previous section, the interaction of an MeV ion with atomic orbital electrons in a semiconductor produces a high density of EHPs along the ion track. The dielectric relaxation time defined as the product of the resistivity times the dielectric constant gives an estimate of the time required to recover the neutrality of the material after the free-carrier injection. If the material is in the relaxation regime, that is, if the dielectric relaxation time is much longer than the carrier lifetime, [12], in presence of an electric field, EHPs pairs are swept out of the device without replenishment from contacts. This occurs in wide bandgap materials, that is, insulators as diamond or semi-insulators as SiC, or in the depletion region in p-n or Schottky junction. Under the relaxation regime, the semiconductor behaves as a capacitor, and the presence of charges in the volume where the electric field is not zero leads to the induction of charge at the electrodes. By virtue of the presence of the electric field, the free carriers drift. In most cases, their velocity is low compared to the velocity of light, so that the magnetic field effects of the moving carriers can be neglected, and the electric field can be regarded as instantaneously propagating. Under these assumptions, the problem can be treated as electrostatics at each moment of charge movement [13 , 14]. Methods for calculation have been developed between the years and to evaluate the instantaneous value of the current induced by moving charges over its entire time of transit in a vacuum tube [16 â€" 18]; the validity of these results was then extended to more general cases in presence of stationary space charge. This theory is then able to model the charge pulse formation in depleted regions of any semiconductor device [19 , 20]. Gunn [21] proposed in the year an expression, deduced under general conditions, for the evaluation of the charges induced upon a system of conductors by the motion of a small charge nearby. The expression 1 is sufficiently general to be used when space charges of variable magnitude are present and hence applicable to any semiconductor junction, whatever is their polarization state [22 , 23]. In order to evaluate the total charge induced at the th electrode, it is sufficient to integrate 1 in time, that is, where are the charge final and initial positions at time and 0, respectively. The procedure to calculate the charge as a function of time is the following. III Finally, the induced charge is evaluated by calculating the GWF at the initial and final points of the carrier trajectory. The validity of 1 and 2 can be easily extended to the case of a continuous distribution of excess free carriers electrons or holes as follows: As a consequence, the contribution of electrons and holes to the induced charge can be evaluated by solving the adjoint equation of the relevant continuity equations. The complete map for any point in the semiconductor domain of induced charge is then obtained by solving a unique for each carrier partial differential equation by numerical typically the finite element, FEM methods. Finally, the knowledge of the induced charge map allows the evaluation of the time evolution of the induced charge generated with an arbitrary distribution of noninteracting particles. It is worth underlying that the validity of this approach stems from the superposition principle, which derives from the assumption that the basic differential equations are linear, that is, the excess charge generated does not significantly perturb the electrostatic field within the device. Such assumption holds only if light H or He ions are considered, but not, in general, in the case of high carrier injection induced, for example, by heavy ions; the Shockley-Ramo-Gunn approach is then unsuitable to interpret effects as plasma delay or funnelling, occurring when semiconductor devices are irradiated with heavy ions. An alternative Monte Carlo approach to realistically model the induced charge pulse formation has been recently presented by Olivero et al. The advantage of this method is that it is suitable to simulate problems involving variables following stochastic distributions, as to simulate electronic noise, statistical fluctuations in carrier generation, or randomly distributed recombination centres. Magnetic or electrostatic quadrupole lenses are used to focus the beam; the best reported resolution to date is less than 0. A magnetic scanning system is used to scan the focused beam over the region of interest, which typically extends to area of mm2. The current induced at the sensing electrode by the motion of the EHPs generated by a single ion is integrated and amplified by a low-noise electronic chain, digitized and recorded by a data acquisition system along with the corresponding spatial coordinates of the ion probe. Details of the nuclear microprobe components and of the experimental procedure can be found in [3]. The induced charge is the usual physical observable imaged as function of the ion strike position. The recent development of waveform digitizers with subnanosecond time resolution enables the study of the time evolution of the induced current. This technique, namely, time- or transient- resolved IBIC TRIBIC , first developed at the Sandia National Laboratories [35], allows the measurement of the carrier transport parameters mobility and lifetime by the deconvolution of the transient current pulses; as an example, the measurement of the risetime of the integrated charge pulse as function of the ion strike position and at different applied bias voltages allows electron and hole mobilities to be mapped [36]. Scheme of the IBIC setup. A MeV ion beam from an accelerator is focused by a quadrupole lens system and scanned over the sample surface using two sets of magnetic or electrostatic plates. The insets on the right sides show the two irradiation geometries: Each incident ion generates a measurable charge pulse, which is amplified and processed by a standard charge sensitive electronic chain. The data acquisition system acquires and stores every event along with the coordinates of the ion. In frontal IBIC, the ion beam is raster scanned onto the sample electrode; this is the traditional and easier irradiation geometry used to obtain two-dimensional images of the charge collection efficiency [37]. In lateral IBIC, a cleaved semiconductor sample is irradiated from the side, in order to generate carriers at different depths beneath the electrode surfaces. It enables more in-depth studies of the motion of induced charges by profiling the charge collection efficiency as a function of the ion beam position with respect to the sensing electrode [38 , 39]. In the following, some significant examples of material characterization, relevant to the semiconductor materials most studied by IBIC, are reviewed. They illustrate the potential of the IBIC technique for the characterization of homogeneous or polycrystalline materials and basic semiconductor devices as metal-semiconductor interfaces, p-n junctions, heterojunction interfaces, and Metal-Oxide-Semiconductor structures. Silicon The first applications of IBIC in the early s were devoted to image device depletion regions through thick metallizations [3 , 8 , 40] in silicon devices. Since p-n junction behaviour is well known and junction devices fabrication is very reproducible, some experiments have been carried out to validate the theoretical model and to develop suitable algorithms to extract data for the electronic characterization of the material. A meaningful example of the evolution of the interpretative model of the IBIC experiments can be extracted from lateral IBIC measurements carried out on commercially available silicon -n- diodes using a low-intensity 5 MeV-proton microbeam [41]. Figure 2 shows the scheme of the experimental setup and the charge collection efficiency CCE profiles relevant to pristine and Au contaminated diodes. The region where the electric field is absent shows exponentially decreasing profiles. A simple drift-diffusion model allowed the extraction of the electronic features of the device, which was arbitrary divided in two main regions. The first region is where the electric field is high and the carrier velocity is close to saturation. This means that all the carriers cross the entire depletion region the region with a nonnull electric field , since the drift time is much shorter than the carrier lifetime. The measurement of the evolution of the CCE plateau width as function of the applied bias voltage allowed the depletion layer width to be estimated and compared with the standard Capacitance-Voltage measurements usually carried out for the determination of the bulk doping profile. For details, see [41]. The carrier transport in the second region is dominated by the diffusion mechanism. Charge carriers generated in this region, where no electric field occurs, diffuse towards the depletion region, where they are subsequently injected in the depletion region, allowing the induced charge signal to be formed. The estimate of the decay rate allowed the diffusion length of the minority carriers in the bulk of the device to be measured. As an example, Figure 2 , elaborated from [41], shows lifetime killing effects induced on the same diode by Au contamination. Afterwards, a more refined model based on the Shockley-Ramo theorem was implemented for the analysis of diodes with nonconstant doping profiles [42]. The importance of diffusion in the formation of the induced charge signal was investigated by Guo et al. Frontal IBIC was extensively used to characterize high power diodes where, in the design process, the knowledge of the electrical field strength distribution is crucial, in order to optimize the termination structure, for example, the floating ring termination. In these experiments, the long range probing depths of MeV protons were exploited to investigate p-n junctions located tens of micrometers below the surface to achieve sufficiently high breakdown voltages of the order of 10 kV [46 , 47]. Silicon-charged particle detectors as passivated implanted planar silicon, PIPS produced by diffused-junction or surface barrier technologies have been extensively studied by IBIC technique to evaluate the detector response and its dependence on operating bias and to quantify ion energy loss in the dead layer and loss of the charge collection efficiency due to trapping centres [48]. A remarkable example of IBIC application and a simple but significant interpretation of the experimental results are given by the study of the ion beam induced charge in Metal-Oxide-Semiconductor MOS structures, which are one of the main building blocks of microelectronic circuits. When carriers are exposed to heavy high energy ions, the movement of carriers generated by ionization results in a change of the voltage on the electrodes, which can lead to the change of the logical state of the microcircuit namely, single event upset, SEU. This is what happens, for examples, in microcircuits working in satellites or spacecrafts which are exposed to high energy cosmic radiation [11]. The silicon-on-insulator SOI technology was supposed to be less prone to SEU from heavy ion strikes than bulk silicon circuits, since the carriers generated in the active region are only a small fraction of the total charge generated by ionization. The interpretation of these results was first carried out by TCAD simulations [52]; however, an exhaustive explanation of the charge induction in MOS structures has been proposed by Vizkelethy et al. In this study, the electronic signal is not the induced charge at the sensing electrode processed by a charge sensitive preamplifier, as in conventional IBIC. Instead, it is the modulation of the source-drain current produced by the effective change of the gate voltage induced by a single ion strike. Hence, the use of a raster scanning MeV ion beam can provide maps of the device sensitivity to ionization radiation impact, resulting in an optimization of the design of space electronics or in the characterization of microdosimeter architectures. Grain boundary effects in polycrystalline silicon solar cells have been analysed by IBIC in numerous researches [55 â€” 61]. The inhomogeneity of the IBIC response is clearly due to the presence of strong recombination effects occurring at the grain boundary. However, it is worthwhile to notice that the low-efficiency region indicated by red colour is a dislocation line which could not be clearly observed in optical microscopy. Grey indicates high charge collection efficiency, and red indicates poorer charge collection efficiency. Reprinted from [57] with permission from Elsevier.

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