E-BEAM FACILITY FOR COLLABORATIVE RESEARCH

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Abstract

An indigenously developed Microtron facility at Mangalore University is being used for variety of research activities in interdisciplinary areas of science and technology. The unique facility with 8 MeV electrons, intense bremsstrahlung photons and neutrons of moderate flux facilitates a number of co-ordinated R&D programs in collaboration with universities and national laboratories. A bird's eye view of all these activities along with a few sample results is presented in this paper..

INTRODUCTION

An 8 MeV Microtron was designed and fabricated by the Raja Ramanna Centre for Advanced Technology (RRCAT) Indore was commissioned at Mangalore University in the year 1995 in order to strengthen the ongoing teaching and research programs in the areas of radiation physics and allied sciences. The versatile accelerator facility delivers 8 MeV electrons with the help of a radiofrequency cavity type I and LaB_6 single crystal (cylindrical) cathode of dimension 3mm X 3mm. The accelerator facilitates a number of R&D programs in collaboration with sister universities of the region and national laboratories.

The first of its kind machine in the country is also capable of delivering intense bremsstrahlung radiation of peak energy 8 MeV and neutrons of reasonably high flux through (γ,n) reaction for variety of applications. The other details of the facility along with salient features are discussed elsewhere [1].

RESEARCH PROGRAMS

A good laboratory infrastructure has been developed for carrying out some of the characterisation experiments in radiation dosimetry, photofission studies, radiation biophysics and radiation processing of materials / devices.

A brief description of the important applications of electron beam from the Microtron facility is mentioned below:

Radiation Effects on Semiconductor Devices

Many semiconductor devices such as diodes, transistors, solar cells, photo-detectors etc., that need to be operated in space or in radiation environment are often subjected to various types of radiation. These components therefore need to be tested for radiation exposure to determine their tolerance and suitability in different applications. The study of the effect of ionizing radiation on semiconductor materials / devices is not only important to have broader understanding of the damage process leading to various modifications, but is essential to assess the device performance when it needs to be operated in radiation environment.

NPN and PNP transistors along with power devices[2,3] have been studied by exposing them to different doses of energetic electrons using the Microtron facility in the beginning and the study was extended to other semiconductor devices to tailor their electrical characteristics by regulating defects formation through graded radiation doses.

p-CdTe/n-CdS thin film solar cells were exposed to electrons and they were characterised in dark and illumination conditions in order to test the device stability in radiation environment. Solar cell parameters like short circuit current, open circuit voltage, fill factor, conversion efficiency, saturation current and ideality factor have been considered. The study reveals that the thin film solar cells exhibit good stability against electron dose up to 100 kGy [4].

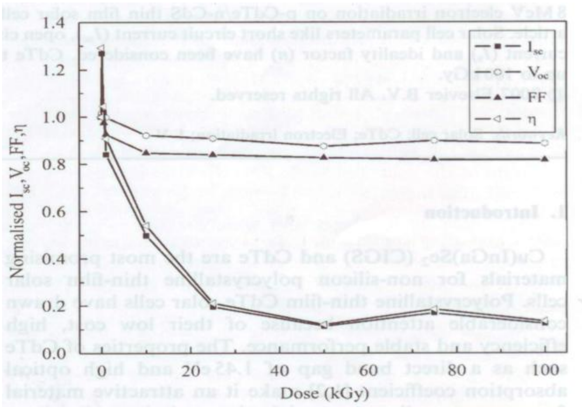

Fig:1: Normalised solar cell parameter as a function of dose

Irradiation studies on p-Si and SS/CdTe/Au Schottky diodes explain that the effect of irradiation is more pronounced at higher voltages than at lower voltages and the main effect of irradiation is reduction in forward current with increasing dose. The degradation in the diode properties may be due to the introduction of radiation induced interfacial defects via displacement damage.

Effect of 8 MeV electrons on Silicon Photo detector fabricated by diffusion of phosphorous into the p-type mono-crystalline silicon wafers of <100> orientation, was carried out. A p+ back surface field layer was created on the rear surface of the silicon wafer by depositing aluminium. As front and back ohmic contacts, metallic coating consisting of titanium, palladium and silver deposited using ion beam sputtering were used. The silicon photo detectors were characterized and the solar cell parameters were determined under dark and AM0 conditions. From the study it is observed that both forward and reverse currents increased systematically with electron dose.

A systematic study on solar cells in radiation environment is being carried out using different varieties of solar cells with different conversion efficiencies. Electrical characterizations at different conditions are being studied extensively in collaboration with UNAM Mexico and NREL, USA.

Radiation Biophysics Studies

The radiation damage of living tissues and cells has attracted attention and the unique radiobiological effects make electron radiation a useful tool for the investigation of radiation damage mechanisms. Even though, biological effectiveness is strongly depending on Linear Energy Transfer (LET) of the radiations, the variations in the effectiveness can be attributed from the energy of the radiation and dose rate, especially for low LET radiations.

Ionizing radiation deposits energy in the form of discrete radiation tracks in cells leading to a spectrum of deoxyribonucleic acid (DNA) lesions along the tracks. These lesions result from either a direct deposition of energy or indirectly via the action of free radicals. Among the various DNA lesions, double-strand breaks (DSBs) are known to be the principal lesion. If DSBs are un-repaired or mis-repaired, gene mutations, chromosomal aberrations, or cell death can occur. The assessment of cytogenetic damage is important to understand the genetic risk in radiation protection. It is also of particular interest in bio-dosimetry, since cytogenetic damage is almost radiation-specific. A number of cytogenetic techniques with potential for dosimetry are employed to quantify the chromosomal damage. Among these, the chromosomal aberration analysis and the micronucleus assay in human peripheral blood lymphocytes (PBLs) are the most reliable techniques.

Electrons become biologically more effective as they lose energy and produce a cluster of ionizations at the end of the track. Monte Carlo track structure data of Nikjoo and Goodhead showed that nearly 50% of the total dose to the medium was attributable to low energy delta rays when irradiated with electrons or photons. Differences in the production of delta rays along the radiation track lead to different degrees of effectiveness. However, the biological effectiveness of ionizing radiation is dependent on the spatial pattern of the energy deposition in nanometer volumes, particularly in DNA. Therefore, the possible microscopic patterns of energy deposition by the primary electrons are very diverse and clearly play a major role in determining the radiobiological effectiveness.

The effects of 8 MeV pulsed electron beam from Microtron on micronuclei (MN) induction at dose rates between 35 Gymin^{-1} and 352.5Gy min^{-1} was systematically studied. These dose rates were achieved by varying electron pulse repetition rate (PRR). Fricke dosimeter was employed to measure the absorbed dose at different PRR and to ensure uniform dose distribution of the electron beam. To study the dose rate effect, blood samples were irradiated to an absorbed dose of (4.7±0.2)Gy at different rates and cytogenetic damage was quantified using the micronucleus assay. The obtained MN frequency showed no dose rate dependence within the studied dose rate range. The earlier dose effect study using 8 MeV electrons from Microtron revealed that the response of MN was linear-quadratic. Therefore, in the event of an accident, dose estimation can be made using linear-quadratic dose response parameters, without adding dose rate as a correction factor.

The mechanism for repairing radiation damage, found in diverse organism, from yeast to humans, is remarkably similar. The universality of these mechanisms makes yeast particularly useful for studying and demonstrating how most cells respond to radiation exposure. An attempt has been made to quantify the dose rate effect on wild type yeast cells Saccharomyces cerevisiae X2180 under euoxic and hypoxic condition using pulsed electron beam from Microtron. From the study on diploid yeast cells it is clear that the presence of oxygen enhance not only the induction of radiation damage but also its efficient repair.

The study on effect of electrons and gamma radiation on MN induction in cytokinesis blocked human PBL was investigated to understand the Relative Biological Effectiveness (RBE) of electron compared with gamma rays. The induction of micronuclei in PBLs exposed to both 8 MeV electrons and Co-60 gamma radiation has been well characterized, with the objective of exploring this endpoint as an indicator of biological damage. Now, measurement of micronuclei is established as a simple technique for determining radiation exposure and an alternative to chromosomal aberration analysis. A dose dependant increase in MN yield is observed as shown in Fig.2. The dose response is similar in low doses and different at doses above 2 Gy.

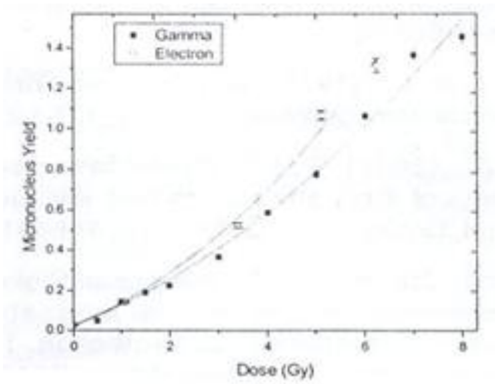

Fig. 2: Dose response curves for MN yield in bi-nucleated human PBL exposed to Co-60 gamma rays and 8 MeV electrons

From the figure, it can be seen that the electrons appear more effective in inducing micronuclei.

The micronucleus assay in human PBL is a sensitive indicator of radiation damage and could serve as a biological dosimeter in evaluating suspected over exposure to ionising radiation. MN frequency as a measure of chromosomal damage has also extensively been employed to quantify the effects of radiation dose rate on biological systems.

Radiation Processing of Materials

Lexan Polycarbonate films - Modifications in the properties of Lexan polycarbonate (Lexan) films exposed to 8 MeV electrons have been studied. The UV-Visible spectroscopy results showed that there is decrease in optical energy gap, optical activation energy and increase in number of carbon atoms per cluster with increase in electron dose. The chemical changes in electron irradiated polymers due to chain-scission and reconstruction have been observed from FTIR spectroscopy results. The correlation of positron lifetime study with optical measurement is obtained and an attempt is made to understand the electron irradiation induced microstructural modifications within the polymer. The XRD pattern shows that the crystallite size and percentage of crystallinity decreases due to the breakage of bonds resulting change of semicrystalline structure of polymer to amorphous. The surface morphology studied by SEM shows the blisters formation of various sizes on electron irradiation and finally gradual degradation in the network structure was also observed.

The a.c conductivity and dielectric constant of the Lexan film were found to increase with increase in electron dose due to the breakage of chemical bonds which increases the number of free radicals. The formation of defects and chromophores, and the presence of impurities, additives and unsaturation have been studied using photoluminescence technique.

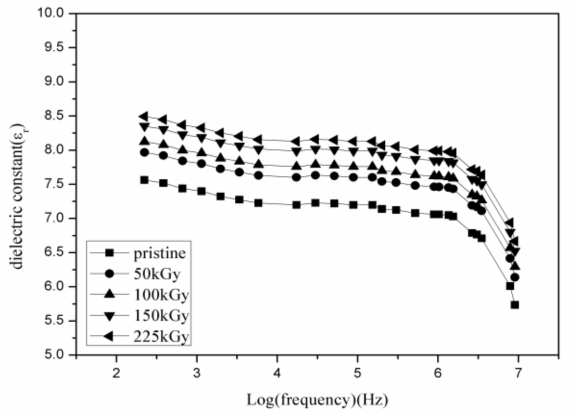

Fig. 4: Variation of dielectric constant with dose

Doped Polymer Electrolyte Films - Electron irradiation effects on sodium fluoride (NaF) doped polyethylene oxide (PEO) films were studied systematically. The changes in the molar extinction coefficient, dipole strength, transition dipole moment and oscillator strength have also been investigated as a function of radiation dose. The optical characterisation carried out provides useful information about the optical behaviour of doped PEO in the influence of radiation which may open up new application avenues.

Polyaniline (PAni) - E-Beam Induced Crystallisation in Interfacially Polymerised Polyaniline (PAni) are observed from UV-Visible spectra, XRD and impedance analysis. PAni crystallises in orthorhombic system at an optimum electron dose 20 kGy, which is the best observed feature. Though there is an improvement in crystallinity in low dose electron irradiated PAni, the conductivity decreases due to the electron induced chain scission, whereas in 40 kGy dose, crosslinking of the polymer chain leads to amorphization.

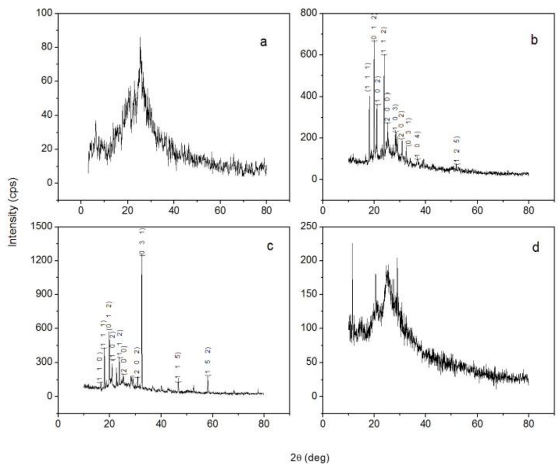

Fig.5: XRD patterns of a) pristine PAni and electron doses b) 5kGy, c) 20kGy and d) 40 kGy

The XRD study of pristine and irradiated PAni is carried out to study the structural modification induced by electron irradiation. A sample XRD pattern with variation for different doses is shown in Fig.5.

Chitosan Preparation by electron beam in the presence of CCl_4 **-** Chitosan which normally undergoes degradation when exposed to electrons can be cross linked when irradiated in the presence of CCl_4. The electron irradiated chitosan have better mechanical properties than that of gamma crosslinked chitosan [5]

Nanoparticles Synthesis

Stable, non toxic Ag nano-particles have been synthesized by irradiating an aqueous solution of AgNO3 and Polyvinyl alcohol (PVA) having two different degree of hydrolysis acting as the stabilizer, with 8 MeV electrons from the Microtron. The rate of formation of nanoparticles could be controlled by changing either the irradiation dosage or the relative concentration of the precursors. The size, shape, and the rate of formation of the nanoparticles depend on the final dosage, as well as the weight ratio of AgNO3 and PVA. The formation of Ag nanoparticles and their size were established through UV–Vis spectroscopy and Transmission Electron Microscopy (TEM) analysis, respectively. Increasing the irradiation dosage seem to favour the formation of polygonal nanostructures. Differential Scanning Calorimetry (DSC) measurements show that there exists a strong interaction between the PVA matrix and the Ag nanoparticles. The method of synthesis of nano particle is a clean method may find these useful for medical applications [6].

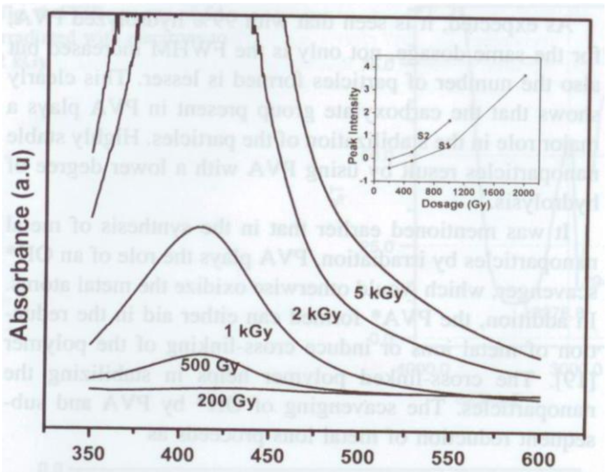

Fig.6: Absorption spectra of AgNO3:PVA for different electron doses. Inset shows variation of peak intensity with dose

Radiation Effect on Quantum Dots **-** A novel one pot synthesis of CdTe quantum dot using hydrothermal technique has been developed using Na_2Teo_3 as Te source and $CdCl_2$ as cadmium source and it has been characterised using XRD, photoluminescence and UV-Visible spectroscopy. The irradiation and other characterisations are in progress.

Photofission Studies

Photofission fragment angular distribution measurements of even-even mass ^{232}Th and odd mass ^{237}Np nuclei were carried out using bremsstrahlung radiation from the microtron. SSNTD technique was used to record the fission tracks. The results reveals that the odd mass nuclei shows nearly isotropic distribution.

FUTURE PLANS

New RF cavity type I will be installed in collaboration with RRCAT Indore for getting better electron beam current from the Microtron to boost R&D activities with higher flux of electrons, photons and neutrons. Detailed neutron based studies on various aspects would be taken up and ongoing activities would be strengthened.

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