Sustained performance of 8 MeV Microtron

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Abstract. Energetic electrons and intense bremsstrahlung radiation from 8 MeV Microtron are being utilized in variety of collaborative research programs in radiation physics and allied sciences involving premier institutions of the country and sister universities of the region. The first of its kind electron accelerator in the country, set up at Mangalore University in collaboration with RRCAT Indore and BARC Mumbai, has been facilitating researchers since its inception with its inherent simplicity, ease of construction, low cost and excellent beam quality. A bird’s eye view on the reliable aspects of the machine, efforts behind the continuous operation of the accelerator and important applications of the accelerator in physical and biological sciences are presented in this paper.

1. Introduction
An 8 MeV Microtron facility at Mangalore University, established in the year 1995, has become a major tool to the researchers from national laboratories and sister universities of the region for their systematic investigations in the area of radiation dosimetry, radiation effects on semiconductor materials and devices, radiation damage studies in biological systems, radiation processing of food items, cross linking of polymers, angular distribution of photo-fission and a number of other research studies in basic and interdisciplinary areas of science and technology. The results obtained have helped to understand the basic mechanism involved in the fundamental processes and have also been useful for application oriented studies. The salient features of the facility are discussed elsewhere [1].

The accelerator with its inherent simplicity, excellent beam quality, easy operation and maintenance aspects has become a focal point for variety of research programs in collaboration with premier laboratories of the country. The first of its kind versatile electron accelerator in the country has been delivering 8 MeV electrons, intense bremsstrahlung radiation of peak energy 8 MeV and neutrons of reasonably high flux successfully in the last one and half decade for conducting advanced research in several frontline areas of radiation physics and allied sciences. All these years, the indigenously developed facility has been maintained with a vacuum level around 7x10⁻⁷ mbar with the help of two sputter ion pumps (270 l/s & 35 l/s) and a turbo-molecular pump (300 l/s). Varieties of smaller experimental (vacuum) chambers were used in varieties of experiments at different vacuum levels.

2. Collaborative Research Programme
A systematic collaborative research program is being conducted through a triangular MoU signed by Mangalore University, RRCAT Indore and BRNS, DAE, Govt. of India. Several research groups from different institutions are involved in this program. A brief account of all these activities along with sample results is given below.
2.1 Dosimetry Studies
Radiation dosimetry plays an important role in any radiation installation. Dosimetry studies have been carried out for high energy photons and electrons using wide varieties of chemical dosimeters along with thermo luminescent dosimeters to measure radiation doses and dose distributions from the Microtron. Frick dosimeter, FBX dosimeter, Glutamine, Alanine and Thermoluminescent dosimeters were used in the study for different dose ranges. An effort is also being made to use different materials as dosimeters based on their behavioural variation in the influence of radiation.

Radiation dosimetry studies have shown the electron beam distribution and its dependence on the beam line magnet fields. Dosimeters are used to obtain the dose details of the machine along with beam distribution along the axis through which it propagates. Several trials of this experiment at different distances from the titanium window showed that the machine has uniform electron beam distribution of 40 mm in either side of the beam axis in vertical and horizontal directions at distances of 30 cm from Titanium window. The distribution was observed without any kind of beam flattener or scatterer.

Thermoluminescent dosimeters were used in radiation mapping of the microtron room and the experiment gave an idea of the radiation environment of the microtron facility inside the microtron room.

2.2 Photo-fission experiments
The angular distribution of $^{237}\text{Np}$ fission fragments was measured over the energy range 7.4 - 9.2 MeV in steps of 0.4 MeV of bremsstrahlung radiation. A vacuum chamber and a target needed for these experiments have been designed and got fabricated in collaboration with Nuclear physics Division and Radiochemistry Division, BARC, Mumbai. Lexan polycarbonate films (SSNTD) were used to detect the fission fragments as the technique is a simple and advantageous over other methods.

![Fig.1. Fission fragments angular distributions of $^{237}\text{Np}$ induced by bremsstrahlung radiation](image)

The photon intensity from the Microtron accelerator at a distance of 15 cm from the bremsstrahlung converter (tantalum target) facility was estimated to be $10^{10}$ photons/s using the code EGS-4. The photofission cross-section was calculated using the angular distribution of fission fragments and the results were compared with those obtained using the code EMPIRE-II and various barrier parameters of the RIPL-1, RIPL-2 libraries and with the new analytical fission barrier formula.
based on the Hugenholtz-Van Hove theorem. The results are in good agreement with the prediction of the RIPL-1 barrier parameter and analytical fission barrier formula [2].

2.3 Studies on Relative Biological Effectiveness
Radiation biophysics study has been initiated to work out all possible physical and biological parameters for bremsstrahlung and electron beam from microtron. Systematic investigations of various parameters influencing biological response of the systems are in progress.

The extent of repairable and irreparable damage in a living cell produced by ionizing radiation depends on the quality of the radiation. In the case of sparsely ionizing radiation, the dose rate and the pattern of energy deposition of the radiation are the important physical factors which can affect the amount of damage in living cells.

Radio-sensitive and radio-resistant bacteria cells were exposed to 8 MeV pulsed electron beam and the efficiency of cell-killing was investigated to evaluate the mean lethal dose. The dose to the cell was delivered in micro-second pulses at an instantaneous dose rate of $2.6 \times 10^5$ Gy/s. The results were compared with those of gamma rays. The survival curve of radio-resistant Deinococcus-radiodurans (DR) is found to be sigmoidal and the survival response for radio-sensitive Escherichia coli (E-coli) is found to be exponential without any shoulder. Comparison of Do values indicate that irradiation with pulsed electron beam resulted in more cell-killing than was observed for gamma irradiation [3].

The differences in the cell survival efficiency and dose rate effect in diploid yeast strains Saccharomyces cerevisiae X2180 and Saccharomyces cerevisiae D7 under euoxic and hypoxic condition have been quantified. Irradiation was carried out using a dose per pulse of 0.6 Gy and pulse width of 2.3 µs, which correspond to an instantaneous dose rate of $2.6 \times 10^5$ Gy/s. A significant difference in the dose response has been observed under euoxic and hypoxic condition. Dose rate effect has been studied by changing the pulse repetition rate of the electrons beam. A significant dose rate effect was observed under euoxic condition for Saccharomyces cerevisiae X2180 but the same was absent under hypoxic condition. The dose rate effect was absent for Saccharomyces cerevisiae D7 under irradiation condition. The survival curves are found to be sigmoidal in shape under both conditions but with a wider shoulder under hypoxic condition. Extensive work in this field of research is in progress.

2.4 Irradiation Effects on Semiconductor Devices
The study on irradiation effects on semiconductor materials and devices was carried out with an aim to investigate modifications in basic characteristics on inducement of damages in semiconductor materials and devices due to high-energy photon/electron irradiation. 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.

A comparative study on the effect of 8MeV electron irradiation on electrical characteristics of CdTe and CIGS thin film solar cells was carried out after having an in-depth study on influence of radiation on different types of solar cells. I-V characteristics of the cells under AM 1.5 illumination condition and capacitance-frequency measurements before and after irradiation were carried out. Solar cell parameters like short circuit current ($I_{sc}$), open circuit voltage ($V_{oc}$), fill factor (FF) and efficiency ($\eta$) were calculated from I-V characteristics. It is found that the efficiency of the CIGS and CdTe solar cells decreases as electron dose is increased to 75 kGy. The other cell parameters such as FF and $V_{oc}$ do not seem to be affected much by irradiation.

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.

![Fig. 2. Normalised solar cell parameter as a function of dose](image)

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 [4].

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.

![Fig. 3. Photoluminescent Spectra of CdTe quantum dots at various electron doses](image)
2.5 Radiation effects on Quantum dots
A novel one pot synthesis of CdTe Quantum dots (QD) using hydrothermal technique has been developed using Na$_2$TeO$_3$ as Te source and CdCl$_2$ as cadmium source. CdTe QD was exposed to various electron doses, ranging from 1kGy to 20 kGy. The characterisations of the samples have shown interesting changes in photoluminescence properties as shown in Figure 3. An increase in emission intensity for doses up to 5 kGy and decrease in emission intensity for doses more than 5 kGy were observed. A Red shift in emission spectra was also observed. [5]

![Fig. 4. Photoluminescent yield (peak) at different electron doses](image)

The results were ascertained using time resolved emission spectroscopy and X-ray photo electron spectroscopy of the QDs. The CdTe QDs can be used in Bio tagging as CdS layer formed (upon irradiation) on CdTe Core is Bio friendly and formation of CdS can enhance photo emission, giving rise to bright emission for easy detection of tagged DNA (any bio material). Detailed studies in this area are in progress.

![Fig. 5. UV-Vis Spectra of AgNO$_3$:PVA at different electron doses](image)
2.6 Nanoparticle Synthesis
Stable, non toxic Ag nano-particles have been synthesized by exposing an aqueous solution of AgNO3 and PVA having two different degree of hydrolysis acting as the stabilizer, to 8 MeV electrons. The rate of formation of nanoparticles was controlled by changing either the electron dose 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 was confirmed by UV–Vis spectroscopy and the nanoparticle size was established through TEM result analysis. Increasing the irradiation dosage seems to favour the formation of polygonal nanostructures. DSC measurements show that there exist a strong interaction between the PVA matrix and the Ag nanoparticles. The method of synthesis of nanoparticle is a clean method may find these useful for medical applications [6].

2.7 Radiation effects on thin films
From the investigations carried out on the electrical behavior of silver particulate films deposited on electron beam irradiated polystyrene (PS) coated substrates held at a temperature of 455K in a vacuum of 8 x10⁻⁶ torr at a constant deposition rate of 0.4 nm/s, it is observed the polymer-metal interaction can be brought about in inert polymers like PS by electron irradiation. Further, it was shown that the morphology is dependent on polymer-metal interaction. The results indicate that the films deposited on PS irradiated to a dose of 20kGy and 25 kGy give rise to smaller clusters with smaller inter-cluster separation, better suited for sensor applications. The induced polymer-metal interaction is attributed to the creation of free radicals due to electron beam irradiation [7,8].

![Optical absorption spectra of Ag films deposited on unirradiated and 50 kGy irradiated PS](image.png)

Fig. 6. Optical absorption spectra of Ag films deposited on unirradiated and 50 kGy irradiated PS

2.8 Radiation Processing
Varieties of polymers and materials have been studied by exposing them to energetic electrons at graded doses. A few of them have been detailed below:

2.8.1 Poly Vinyl Alcohol
PVA is a widely used, non-toxic, water soluble, biocompatible, and biodegradable synthetic polymer with excellent mechanical properties such as flexibility and good film forming quality with excellent gas barrier ability [9]. Irradiation effects on the microstructural parameters in PVA films have been studied using Wide Angle X-ray Scattering (WAXS) data. The crystal imperfection parameters like crystal size <N>, lattice strain (g in %) and enthalpy (°) have been determined by Line Profile Analysis (LPA) using Fourier method of Warren.
From WAXS study, significant change in the values of micro structural parameters was observed after irradiation even though there was not much change in the position of the X-ray reflection. The crystallinity of the polymer also found to be decreasing with increase of radiation dose.

2.8.2 Polyaniline (PAni)

Electron beam irradiation of PAni has yielded crystallisation in interfacially polymerised polyaniline. This was ascertained 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. The impedance analysis of PAni after irradiating it to different doses, gives Nyquist plots.

The above figure shows the Nyquist plots of pristine, 5, 20 and 40 kGy dose electron irradiated PAniananomaterial. The pristine PAni shows a single semi circle indicating a single relaxation process. In the 5 kGy dose irradiated PAni, the Nyquist plot shows a single semi circle with a pseudocapacitance loop at low frequency region. Interfacially polymerised PAni irradiated with 8 MeV electron beam shows electron induced chain scission at low doses and crosslinking. The structural change is also reflected in the electrical properties of PAni. This can be seen in the 20 kGy dose, in which the formation of subgrains results in
two semicircles–grain boundary and grain interior arcs. It is concluded that the crystalline polyaniline can be obtained by 8 MeV electron beam irradiation for which 20 kGy is the optimal dose [10].

2.8.3 PMMA
Free volume related fluorescence properties of electron irradiated chalcone doped PMMA films have been studied using positron annihilation and fluorescence spectroscopic techniques. In this polymer composite, enhancement of fluorescence at lower doses and reduction at higher doses has been observed under electron irradiation. From Positron annihilation studies suggests that at lower doses of irradiation induced crosslinking which affect the free volume properties and inturn hinders the chalcone molecular rotation. At higher doses chain scission process affect matrix relaxation. Under the restricted condition the chromophore molecules likely to emit enhanced fluorescence and its mobility is directly related to the free volume around it [11].

2.8.4 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. DSC studies showed a decrease in glass transition temperature and heat of fusion after irradiation due to chain-scission which indicates polymer was moving towards more disordered state. Thermal decomposition temperature of Lexan polycarbonate increases upon irradiation.

![DSC thermogram for the pristine and electron-irradiated Lexan films](image)

Fig. 9. DSC thermogram for the pristine and electron-irradiated Lexan films

The glass transition temperature ($T_g$) for the pristine sample was around 150ºC. At the dose of 100 kGy, the DSC curve showed a shift of $T_g$ to 146ºC, and for 225 kGy, $T_g$ was observed at 143ºC. After irradiation, the shift of $T_g$ to lower temperature reveals that electron irradiation leads to chain scission and subsequently to reduction in molecular weight. As a result, the polymeric system was changing towards a more disordered state [12].
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.

Several other collaborative research activities in the area of materials science, fisheries, radiobiology, radio-protectiveness of various plant extracts, radiation processing of ayurvedic medicines for shelf life increasal and other related aspects are also being carried out.

3. Program for users
Workshops, Seminars and Users Meeting on different areas of research are being organized to encourage both in building up the laboratory facilities and to use the facility for carrying out front-line research in the field.

4. Future plans
Up-gradation of the existing accelerator facility with higher beam power to cater to the needs of the Microtron Users is planned with the support of BRNS. Detailed neutron based studies on various aspects would be taken up and ongoing activities would be strengthened. It is also planned to extend the Microtron facility to postgraduate students for their laboratory experiments / project works.

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