8

Gamma Radiation Induced Electrical Response of $PbZrTiO_3$ Varactor

8.1 INTRODUCTION

Recently strong interest has focused on the development of tunable dielectric materials for frequency agile RF and microwave device applications [Subramanyam *et al*, 2013; Im *et al*, 2000]. Ferroelectric materials are characterized by a high permittivity, electric-field tunability and non-hysteretic operation, which make them appropriate for tunable microwave devices. Ferroelectric varactors have been realized in a number of components such as tunable filters, antennas and phase shifters [Nath *et al,* 2005; Poplavko *et al,* 2000]. Structural and micro-structural quality is directly correlated to the leakage current characteristics of the film which is an important parameter to occur dielectric breakdown of pervoskite oxide thin film. The films improved tunability at particular bias field must be validated by assessing the leakage current at this same applied dc bias as the leakage current is strongly governed by applied electric field. Based on the device impedance matching, dielectric constant <500 and control voltage <10 V are compatible with the voltage requirements of semiconductor based system for a phase shifter and other tunable device applications. Exceeding the required values for microwave components in integrated circuits causes complications, in turn lead to less efficient power transfer thereby degrading device performance. Ferroelectric varactors have many advantage such as frequency independent tunability, low leakage currents, high tuning speed and dc control power, high breakdown field, and radiation hardness.

Lead zirconate titanate thin films have emerged as leading candidates among the various tunable ferroelectric materials, for such applications, due to their highly nonlinear dielectric response to an applied electric field [Kingon *et al,* 2005]. Great efforts have already been made by researchers in order to reduce the dielectric loss of PZT thin films by doping with various elements (La^{2+}, Sr^{2+} etc) [Liu *et al,* 2013; Wang *et al,* 2006]. Significant efforts have also been devoted to maintain the high dielectric tunability and to decrease the dielectric loss through epitaxial thin film growth and by constructing a variety of composite structures [Kong *et al*, 2010; Lu *et al,* 2003]. In addition to the high tunability on epitaxial ferroelectric materials, numerous experiments revealed that the dielectric properties in the thin film were also strongly affected by ionizing radiations [Hu *et* al, 2000; Lee *et* al, 2001; Gao *et* al, 2000]. Metals and semiconductors have been extensively studied for their irradiation effects since precise influence of the irradiation effect on functional properties and microstructure of metal oxides is difficult to investigate due to their complex physicochemical nature. Functional ferroelectrics with perovskite structure are usually the complex oxides, consisting of two or more cations with different chemical natures. It is imperative to characterize the response of the active (ferroelectric) material as a function of radiation dose in order to assess the device behavior and functionality for operating in locations with high radiation exposure. Irradiation-related effects have received some attention in the past decade and electrical properties of the ferroelectric materials have been widely investigated for use of them under irradiation environment conditions such as space application, military system, and nuclear reactors.

Radiation hardness of BST thin films was evaluated for its dielectric properties in the kHz and microwave-range and reported that microstructure was the major governing parameter to control the radiation damage in BST films which was successfully tuned to achieve radiation hardened films. The ferroelectric Lead Zirconate Titanate (PZT) thin films have been studied [Scott *et al*, 1989; Lee *et al,* 1992] and observed high radiation hardness of the films than other Si-based electronic device materials. Scott *et. al.* reported gamma-ray and X-ray irradiation effects on the switching properties of PZT thin films and showed that the radiation hardness of the PZT thin film exceeded 50 kGy total doses. The irradiation effects on the polarization retention and loop symmetry was observed which was attributed to the creation of the irradiation-induced charges near the film surfaces [Schwank *et* al, 1990]. Recently, the interest in these ferroelectric complex perovskite oxide thin films has been reviewed and the irradiation hardness was evaluated in terms of the electronic properties, where it was shown that the microstructure and phase-purity of the films plays important role on the radiation induced changes [Bastani *et al*, 2013]. However, despite the radiation hardness of the ferroelectric materials, the radiation-induced degradation of ferroelectric properties has been extensively studied to get the good performance during operational lifetime of the devices. Ionizing effects and atom displacement effects are the two main factors for which is generally thought to produce defects, affecting the device properties. These defects can be resulting into pinning of the domain walls by easily accumulating along the domain walls and grain boundaries. Large amounts of the electron–hole pairs could also be generated by ionizing effects, in-turn creating local field opposite to the direction of external field due to trapped charges, ultimately resulting in the degradation of the polarization switching. Guoqiang *et. al.* has shown radiation-induced reduction in the maximum dielectric constants and distortion of the C–V curve [Zhang *et al,* 2003]. A significant leakage current was observed for radiation irradiated $BaSrTiO_3$ thin film capacitors due to radiation induced phenomena [Yan *et al*, 2015].

However, radiation hardness is regarded as an important limiting factor for these applications, and should be comprehended carefully before practical use in such hostile environments. Various tunable high frequency capacitor have been investigated by researchers and dielectric varactor has been proved as a best alternate with low voltage tunability, highest miniaturization potential and low cost [Tiggelman *et al*, 2009]. Defects including structural, point, vacancy, grain boundary etc. in dielectric layer put an impact on polarization behavior, acting as a pinning center for ferroelectric domain, mainly grain boundaries, where extrinsic contribution plays dominant role, compare to intrinsic one , can mask the contribution from volume of grains. Defects act as a scattering center for charge carriers, that reduces carrier mobility and limit the performance of electronic device [Shchukin and Ledentsov, 2006]. Epitaxial films are expected to have high crystalline quality with minimal extrinsic contribution, caused by defects and measurement on epitaxial layer shows very close to intrinsic characteristics of the dielectric varactor as compare to polycrystalline film [Vrejoiu *et al*, 2006]. However, to the best of our knowledge, no report is evident on gamma irradiated epitaxial PZT varactor. Hence the growth of epitaxial thin film may be worth to investigate the intrinsic behavior of varactor to measure the influence on dielectric properties by ionizing radiation induced defects.

In this Chapter, we attempted to investigate gamma irradiation effects on intrinsic dielectric properties of defect free epitaxial PZT/SRO thin film varactor, deposited by PLD technique for high tunable applications. The Pt electrodes were subsequently defined on top, using photolithography technique for electrical measurements. The present trend of electronic miniaturization requires scaling down the area of ferroelectric system. Therefore in order to decrease short circuit paths and increase rise times, varactors were fabricated with submicron dimensions using lift-off technique. In addition variations of the tunability, loss tangent and effective C-V response was studied for PZT film varactor as a function of gamma-ray irradiation doses from 0 kGy to 400 kGy.

8.2 Pt ELECTRODE PATTERENING ON $PbZrTiO_3/SrRuO_3$ FILMS

The 250 nm thick epitaxial $PbZr_{0.52}Ti_{0.48}O_3$ (PZT) films are deposited on single crystalline $SrTiO_3$ (100) substrate and sandwiched between 100 nm $SrRuO_3$ (SRO) and Pt electrodes. PZT heterostructures were patterned on single crystalline STO substrates using a structured amorphous aluminum oxide (AlOx) layer as sacrificial template mask, which is capable of withstanding high temperatures. First, the $SrRuO_3$ film was deposited via PLD before the AlO_x mask layer deposition and patterning for fabrication of heterostructure capacitors on top of a $SrRuO_3$ conducting bottom electrode. A thin layer of AlOx was deposited on the SRO/STO using pulsed laser ablation. A single crystalline Al_2O_3 target was ablated at room temperature using a high energy KrF excimer laser of 248 nm wavelength with a typical pulse length of 20 - 30 ns. The deposition time and repetition rate was adjusted in order to obtain the required thickness. In the next step, a positive photoresist layer was spin coated (~ 1.2 µm thick) and patterned with a conventional photolithographic process. The standard photoresist-developer solution is a basic solution and reacts with the AlOx mask layer forming water soluble alkali-metal aluminates. Hence, while developing the photoresist pattern (after ultra-violate light exposure) the underlying alumina layer also develops and dissolves in the water. This mimics the photoresist pattern in the AlOx layer and opens up selective areas on the substrate, where the perovskite materials can be deposited at high temperatures. The remaining photoresist was removed using organic solvents leaving substrates with a patterned amorphous alumina layer. The whole lithographic procedure was performed in a clean-room environment to minimize any contamination. Substrates covered with patterned amorphous aluminum oxide layers were subjected to deposition of multilayer perovskite heterostructures at high temperatures by PLD, resulting in epitaxial growth in uncovered areas.

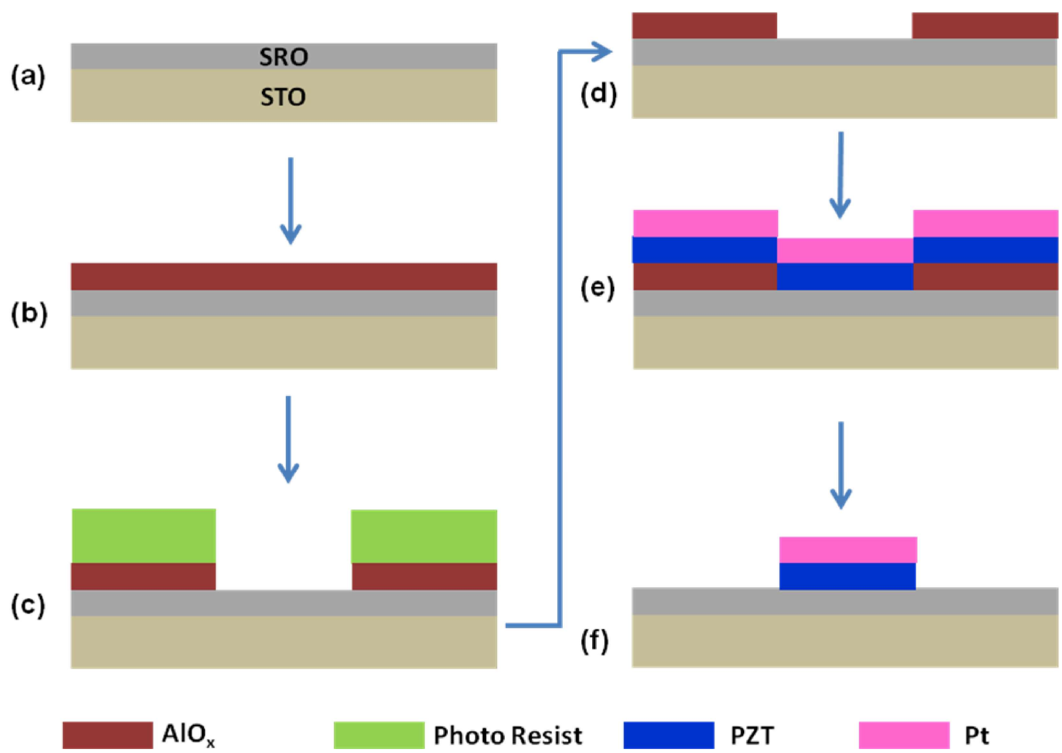


Figure 8.1: Schematic illustration of the patterning process of $PbZr_{0.52}Ti_{0.48}O_3$ films

After high temperature deposition of oxide multilayers and subsequent controlled cooling down to room temperature the samples were treated with a 4 M NaOH solution, which dissolved the sacrificial AlO_x template as alkali metal aluminate in the solution with simultaneous removal of the amorphous oxides deposited on top of it. This leads to a one step removal of all unwanted oxide layers and produces the desired pattern directly. Finally the samples with perovskite patterns were cleaned with deionized water several times in order to remove any surface contamination. There were three capacitor electrode were patterned of the area $4x10^{-4}$ cm^2, $1x10^{-4}$ cm^2 and $0.25x10^{-4}$ cm^2 as shown in Figure 8.2.

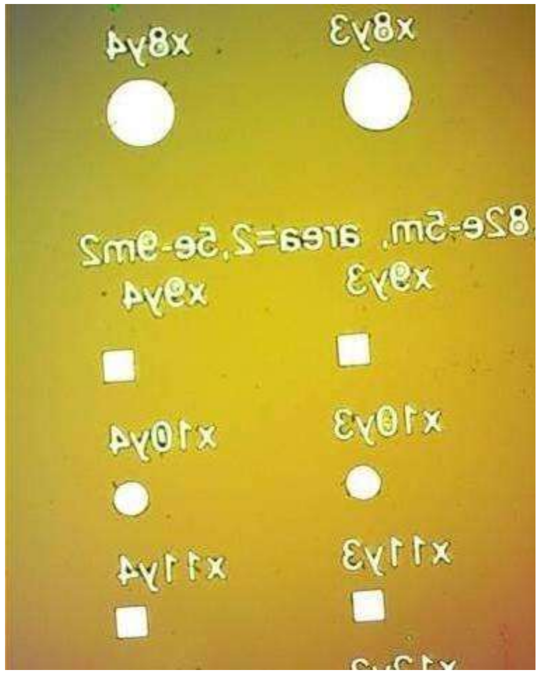


Figure 8.2: Optical photomicrograph of PZT capacitor

8.3 CAPACITANCE-VOLTAGE MEASUREMENT OF PZT VARACTOR

Ferroelectric capacitance voltage (C-V) and current voltage (I-V) curves were acquired using an SCS 4200 Kiethley system for discrete frequencies from 100 kHz to 500 kHz with small ac signal amplitude of 30 mV. The schematic view of PZT varactor is shown in Figure 8.3. The applied bias voltage was swept from negative bias voltage (–10 V) to positive bias voltage (+10 V) and vice versa at a rate of 0.25 V/s.

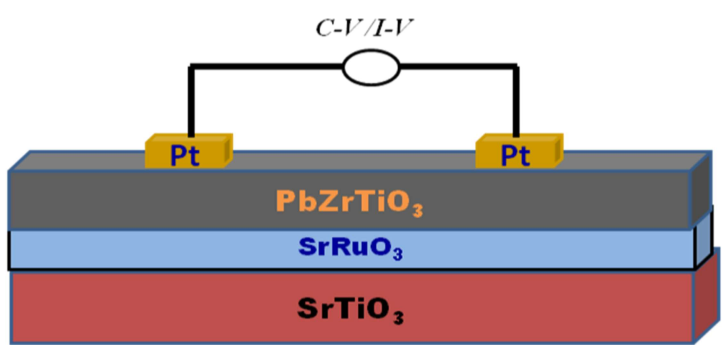


Figure 8.3: Schematic view of Pt/PZT/Pt varactor

The C-V characteristics of the PZT varactors were investigated and a strong dependence of capacitance on the dc bias field was observed. Figures 8.4 and 8.5 shows the capacitance versus applied bias voltage at two different area capacitor at 100 kHz and 500 kHz frequency for the pristine PZT thin films. The film exhibits a good symmetry and butterfly-shaped C-V dependence which reflects contribution of domain wall oscillation to dielectric properties, the enhancement "in plane" ferroelectric property of the PZT based device [Wang *et al*, 2005].

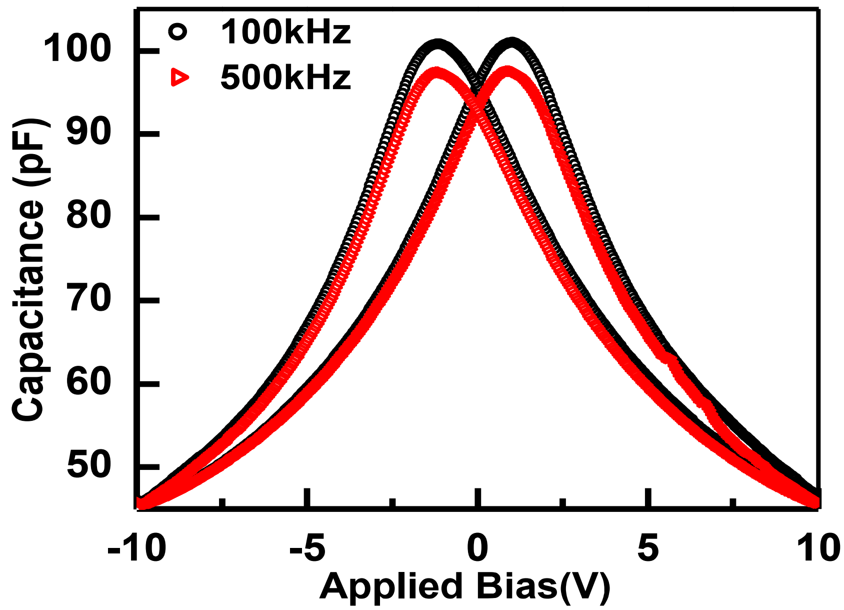


Figure 8.4: C-V characteristics of epitaxial PZT varactor device with capacitor area 1x10^{-4} cm^2

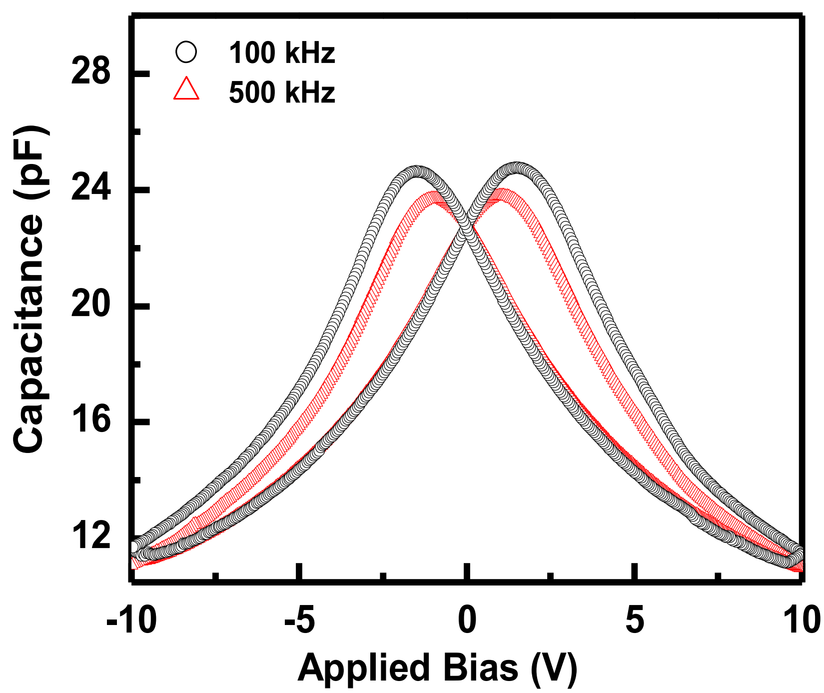


Figure 8.5: C-V characteristics of epitaxial PZT varactor device with smaller capacitor of 0.25x10-4 cm^2 area

The capacitance of varactor is associated with domain reorientation process where domain switching occurs from one state to the other with applied bias when dc bias is swept from negative to positive bias and back [Sharma *et al*, 1999]. The main contribution to the high capacitance value is due to the domain wall vibration at low applied field. The peak value of capacitance corresponds to coercive field which is due to a high domain wall density and motion, known as the extrinsic properties of the varactor. For high field, most of domains have already aligned along the direction of the applied field and capacitance is small which is determined by vibration of dipoles. Therefore it is reasonably accepted that reduction in domain wall density is the reason behind decrease in the capacitance. The maximum value of capacitance (C_P) of the varactor of pristine PZT varactor was measured 100 pF with maximum dissipation factor (tan δ) of 0.04 at 100 kHz frequency for electrode area of $1x10^{-4}$ cm^2. The ferroelectric measurements of heteroepitaxial PZT (001) capacitor devices show stable and high quality ferroelectric response. The capacitance was also measured on different area capacitor to see the effect of increasing area and shown in Figure 8.6. It is observed that the capacitance increases with increasing the value of capacitor electrode area.

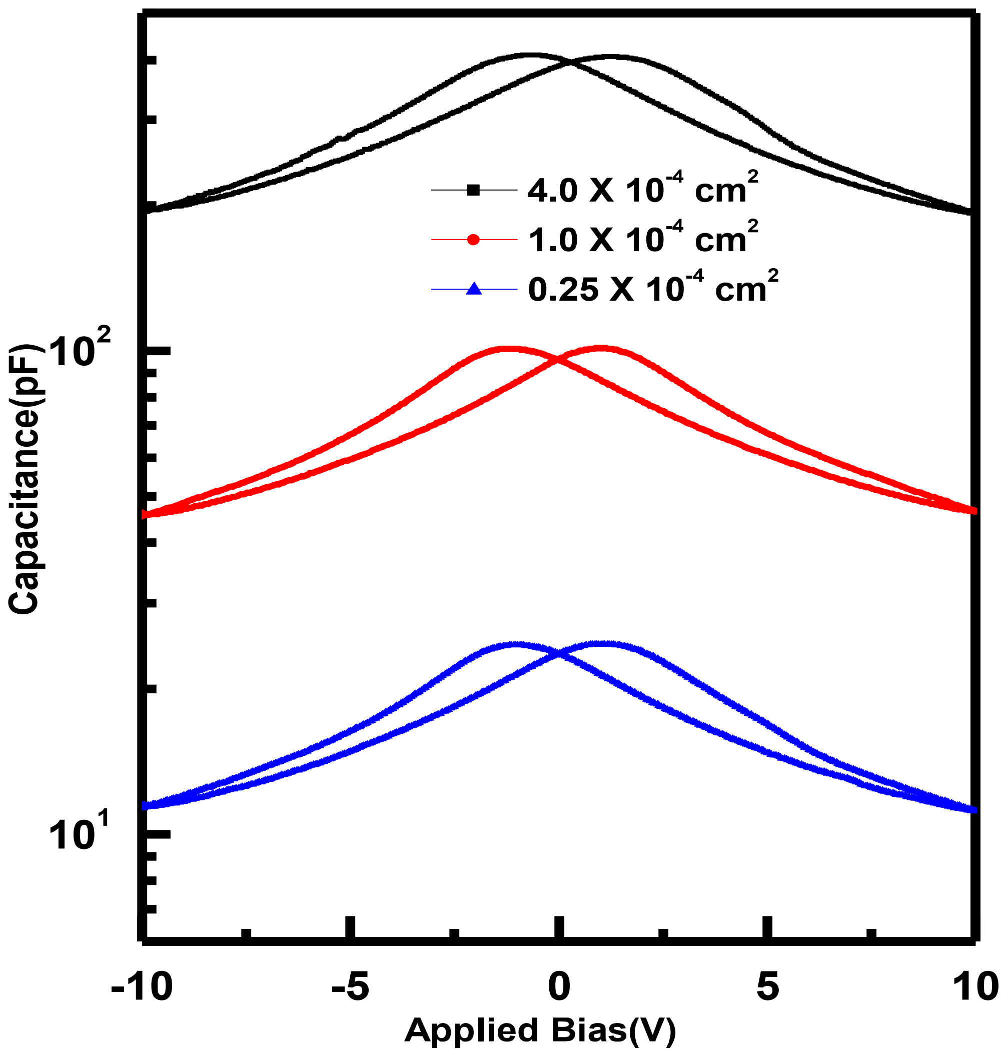


Figure 8.6: C-V characteristics for three different capacitor areas at 100kHz frequency

The frequency dependence on the normalized capacitance and loss tangent of the PZT varactor is shown in Figure. 8.7. The dielectric properties could not show any appreciable dispersion with measured frequency up to 500 kHz, reflects good quality film and reducing extrinsic contribution. Figure 8.7 shows a dielectric loss (tan δ) and capacitance with frequency sweep from 5 kHz to 500 kHz of the PZT film varactor. The device capacitance is higher at lower frequency due to contribution from space charge polarization while capacitance reduced slowly with an increasing frequency. Dielectric relaxation in the low frequency range can be attributed by the ionic space charge such as oxygen vacancies, defects and interfacial polarization. It was evidenced that oxygen vacancy plays crucial role in dielectric degradation of PZT films. A gradual increase in tan δ values was observed in a high frequency (>100 kHz) due to finite resistance of interface between the film and electrode and the capacitive coupling of grain boundaries with dipoles [Joshi and Krupanidhi, 1993].

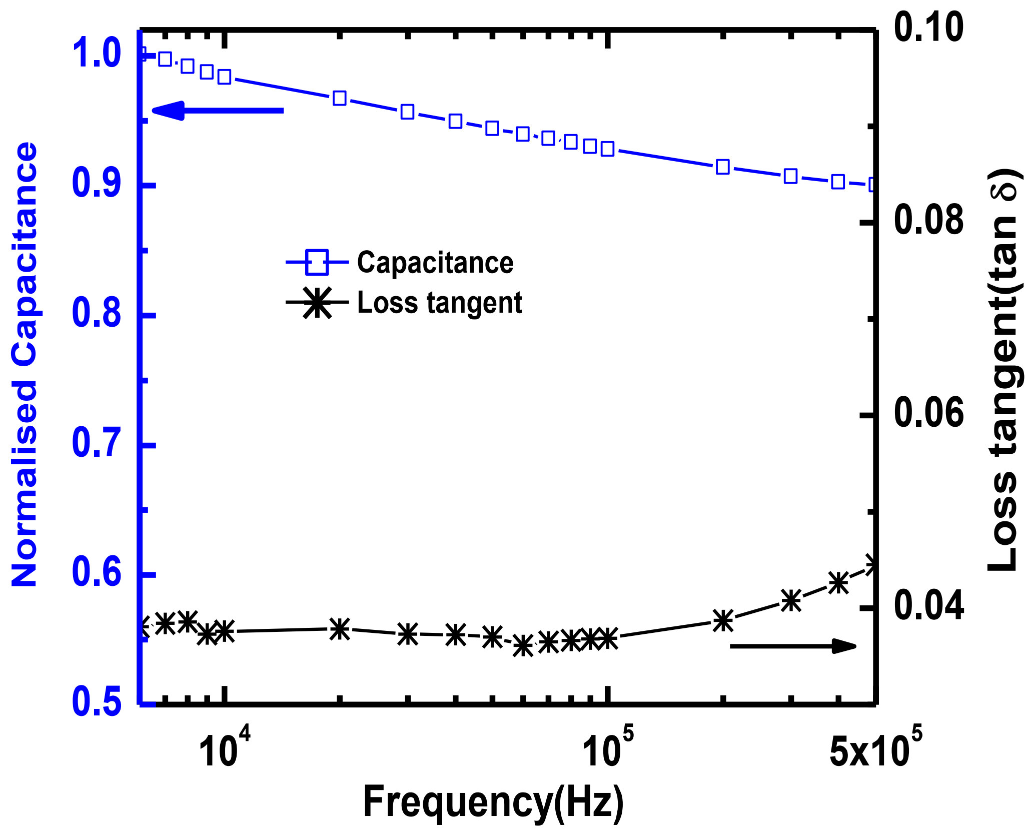
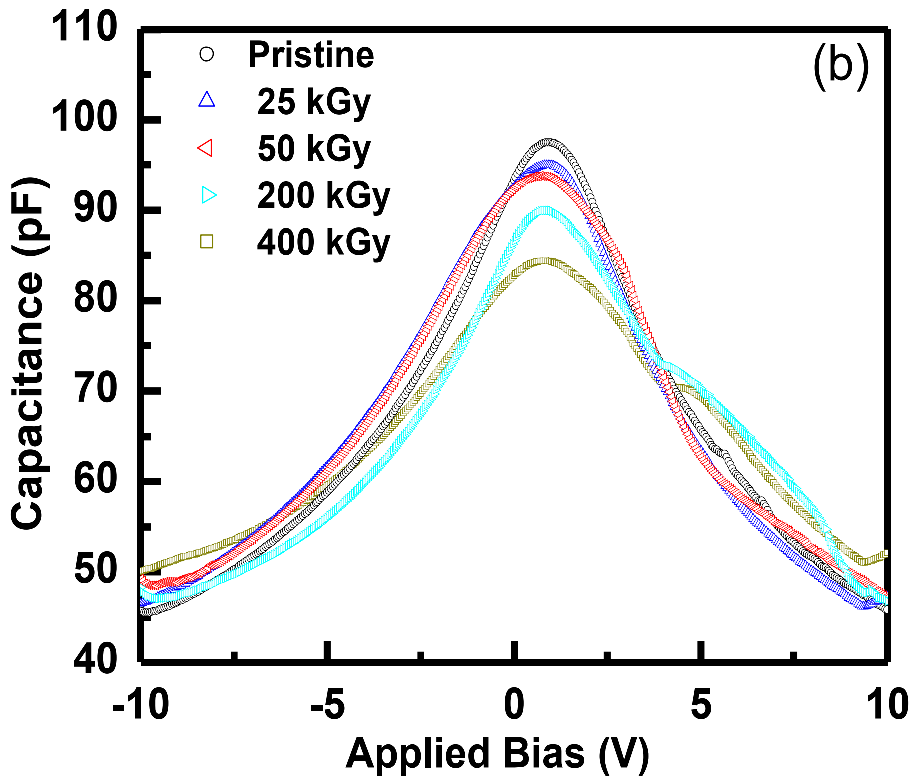


Figure8.7: Normalized Capacitance and dielectric loss(tan δ) of pristine epitaxial PZT as a function of frequency

8.4 GAMMA IRRADIATION EFFECT ON DIELECTRIC RESPONSE OF Pt/PZT VARACTOR

The epitaxial Pt/PZT varactor films were irradiated using gamma-ray ^{60}Co source at room temperature with different total doses from 0 kGy (Pristine) to 400 kGy. The devices were exposed to gamma irradiation at a dose rate of 3 kGy/h for post irradiation study. The electrical properties of the device were measured as a function of gamma-ray irradiated dose. Figures 8.8 and 8.9 show the C-V behaviour of the PZT based varactor devices as a function of the applied bias for different total dose and voltages (swept from negative to positive direction).

The measurements were carried out with a constant time difference to account for prolonged generation of defects after irradiation at different gamma exposure doses. The C-V characteristics, loss tangent and leakage current of the varactors were observed before and after the gamma-irradiation from 0 kGy to 400 kGy doses. The samples were left unbiased during irradiation and all exposures were performed. The measurements were taken at two different frequencies of 100 kHz and 500 kHz. It can be seen from the C-V reposnse curve that the maxima of the curve decreases significantly alongwith small negative shift at higher radiation doses. Similar trend was observed for both capacitance and loss tangent in exposure to higher gamma-irradiation. The measurements were performed on two different areas of 0.25x10^{-4} cm^2 and 1x10^{-4} cm^2 to avoid any hidden role on the device properties after gamma exposure.



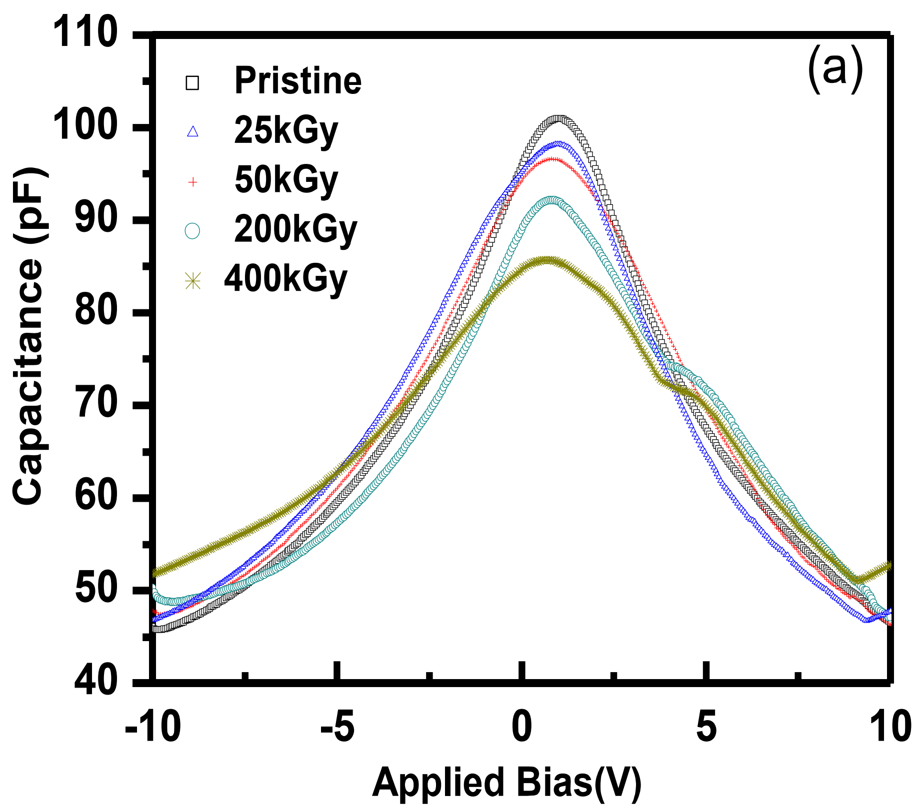


Figure 8.8: Influence of gamma irradiation on C-V characteristics of large area varactor of 1x 10^{-4} cm^2 (a) 100 kHz and (b) 500 kHz with different gamma doses from 0 kGy to 400 kGy

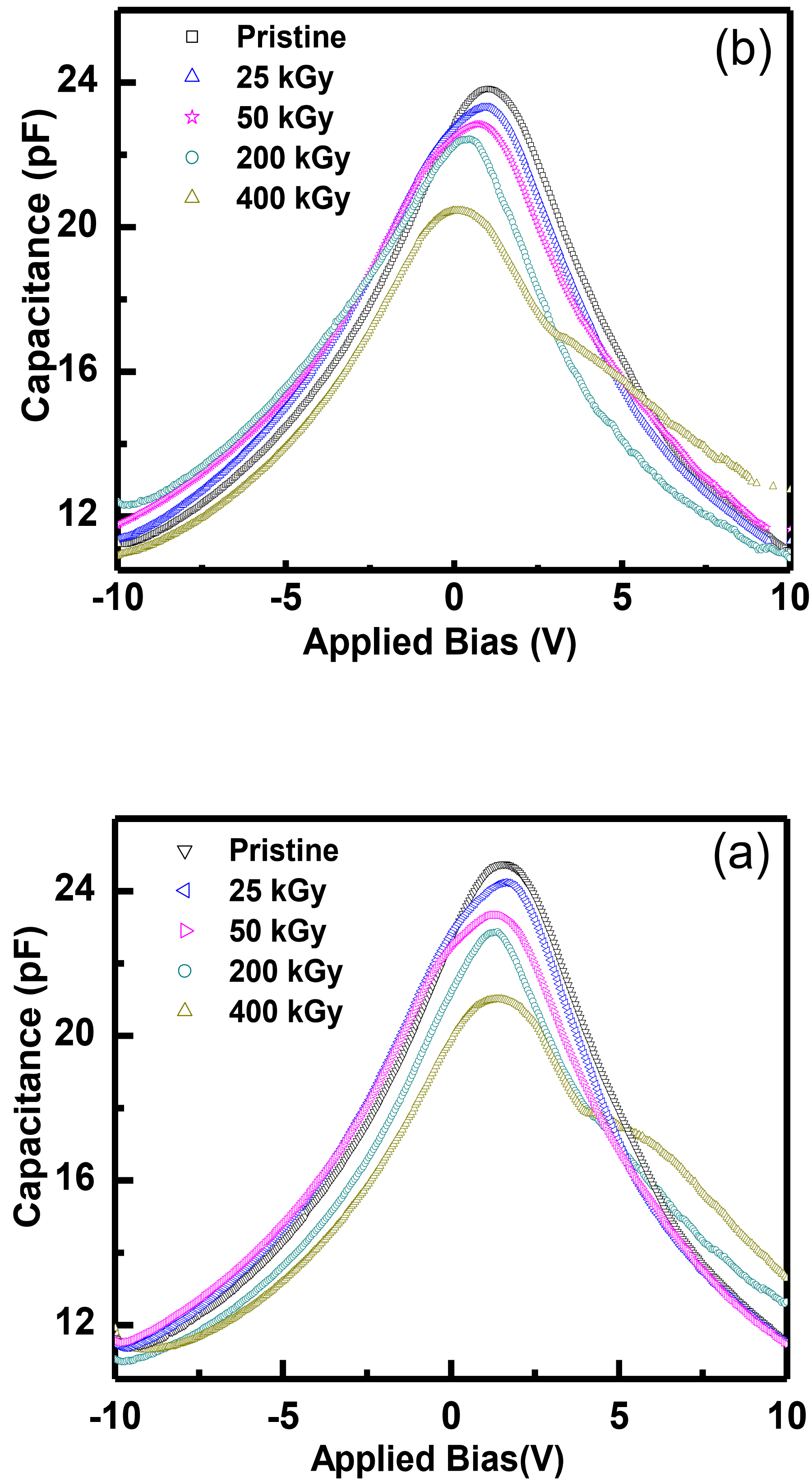


Figure 8.9: Influence of gamma irradiation on C-V characteristics of small area varactor of 0.25x 10^{-4} cm^2 (a) 100 kHz and (b) 500 kHz with different gamma doses from 0 kGy to 400 kGy

All measurements were repeated on five similar devices for different frequency from 100 kHz to 500 kHz at each radiation dose for statistical relevance. However, the decrease in capacitance after gamma irradiation to higher doses appears to be due to a different mechanism. Higher doses of gamma-radiation may cause point defects due to redistribution of gamma-radiation energy over the sample. This would suppress the polarization properties and migration of defects. Such effects are more pronounced in binary and ternary oxide materials as proposed by Mekhtieva *et al* and Habib *et al* [Mekhtieva *et. al*, 2002; Habib *et al*, 2014]. Together these results showed us that, somehow, radiation induced defects diminish the dielectric behaviour of the PZT while also suppressing loss mechanisms [[Miclea *et al*, 2005; Toacsan *et al*, 2007]. The migration of vacancies is likely to occur toward defect site, around the value of field needed to switch the domain, because this would be when vacancies are most mobile. It is understood that the oxygen vacancies plays crucial role in stabilizing defects to act as pining sites. There may be resulting distortion of the oxygen octahedron around cation when the oxygen vacancies become associated with the defect site which is thought to be stablise the defect and considered an effective domain wall pining site. Therefore the domain has been rendered un-swicthable and overall polarization decrease [Warraen *et al*, 1994]. However, formation of interfacial layers near the film electrode interfaces due to effect of accumulation of oxygen vacancies after gamma irradiation causes another mechanism to reduce polarization [Larsen *et al*, 1994]. Hence decrease in polarization or capacitance is thought to be because of accumulation which reduces total applied electric field across the ferroelectric capacitor. Oxygen mobile vacancies moves toward top or bottom electrode under applied negative or positive bias on top electrode. The mobile charged defects like oxygen vacancies are easily accumulated near film electrode interfaces [Matthew and Scott, 2000] because of large mobility as compared to Lead and form interfacial layer under an applied electric field [Jiang *et al*, 2002 and Chen *et al*, 1994].

Transport and trapping of radiation induced charges at grain/domain boundaries, defect site near electrode/PZT interface and within PZT may be responsible for negative shift of the C–V curves [Benedetto *et al*, 1990]. A non-zero local field is produced by spontaneous polarization at grain/domain boundaries and mobile charge carriers including radiation generated carriers can be trapped at these defects sites. The electron-hole pairs will be separated by local field when the ferroelectric capacitor is without an external bias [Coic *et al*, 1994]. Larger numbers of holes are trapped by defects near the domain and grains boundaries form positive trapped charges while the electrons are swept out by the local field. At the same time, internal space charge field is produced in the PZT film by the radiation-induced positive trapped charges with increasing the radiation doses. More positive trapped charges are generated to develop internal space charge field to counter the external applied bias field, causes a negative shift of C–V curves along the voltage axis. The trapped charges continue to build up with increasing dose, leading to the reduction in capacitance and loss tangent with total radiation dose. It is to be noted that increasing fraction of the ferroelectric domains may actually become ''locked in'' by the internal space charge field, preventing them from switch in response to the external applied bias. The FWHM of (001) diffraction peak varied gradually from 0.148 to 0.168 with increased gamma dose from 0 kGy to 200 kGy respectively, which reflects decreases in crystallinity of PZT film which is related to defects, mentioned in previous chapter. The increase of defect density may cause the decrease of dipole moment within the PZT epitaxial layer, leading to lower capacitance of the PZT varactor with the increase of the irradiation dose [Kim *et al*, 2015]. Also similar behaviour was observed for different area electrode irrespective to difference in electrode area. The C–V characteristics were distorted with higher dose of 200 kGy and 400 kGy.

Switching behaviour of ferroelectric material is phenomenon of domain nucleation, domain growth and domain wall motion. The switching time for domains in PZT is usually in the range of few hundred nano seconds which suggest that the frequency below 1 MHz provides sufficient time for full switching of the polarisation to follow frequency. In order to investigate how the capacitance or polarisation depends on frequency, capacitance -frequency behaviour were recorded after gamma irradiation in the range from 0 kGy to 400 kGy radiation dose. Figure 8.10 shows frequency dependence of the capacitance at different gamma dose. It was observed that capacitance value is decreases with increasing gamma dose. A similar trend was reflected from the measurement which shows that gamma radiation induced defects are responsible to restrict domain switching. The domain wall pining due to radiation plays crucial role on dielectric properties.

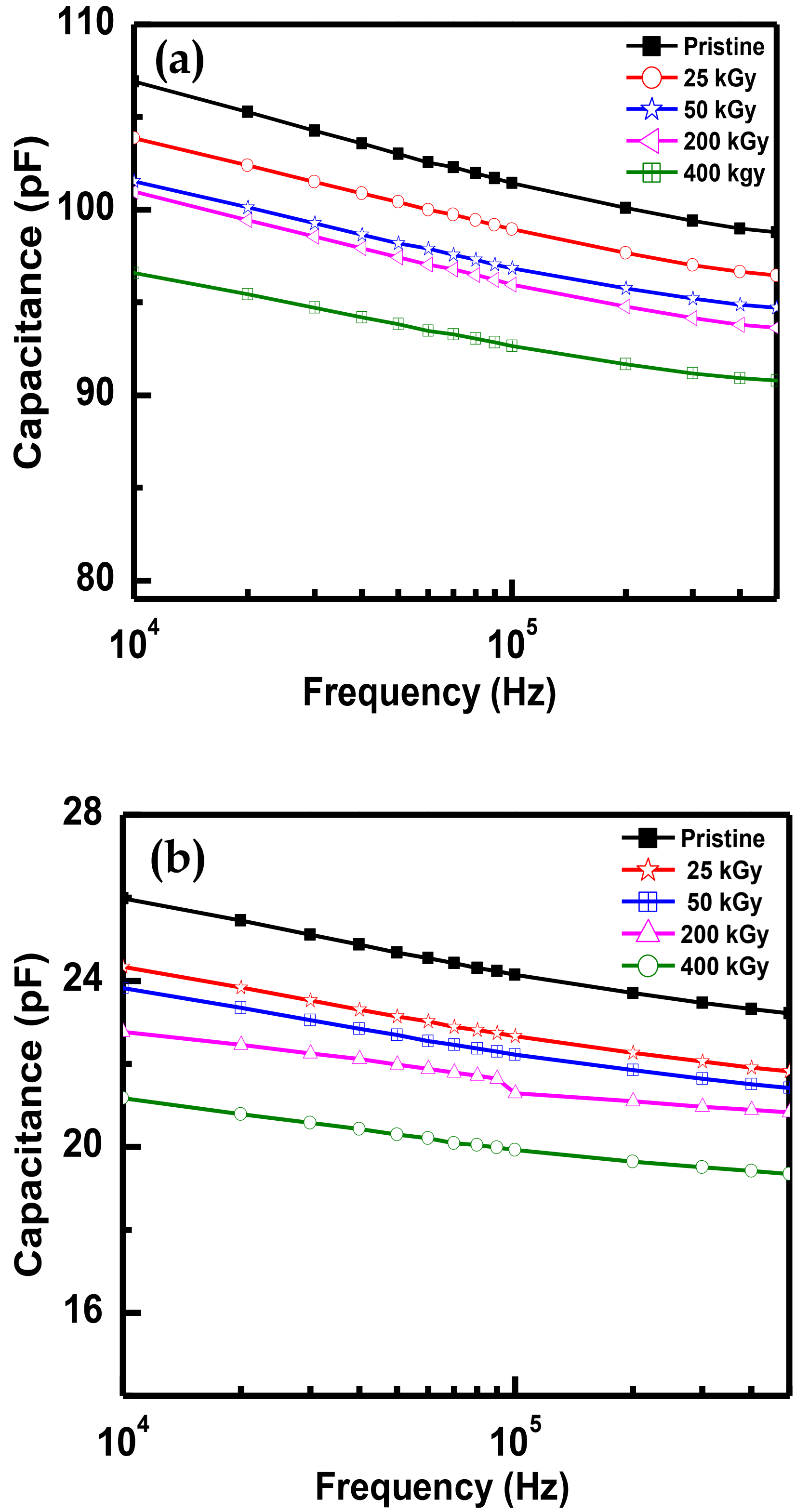


Figure 8.10: Influence of gamma irradiation on capacitance of PZT varactor as a function of frequency at different gamma doses from 0 kGy to 400 kGy for capacitor area (a) 1 x 10^{-4} and (b) 0.25x 10^{-4} cm^2

The evolution of the dielectric loss of the varactor as a function of frequency and applied bias before and after irradiation are plotted in Figure 8.11 and 8.12 respectively for different total dose. The loss tangent and frequency characteristic exhibits a decrease with higher gamma dose, which may be stemmed from the radiation induced defects.

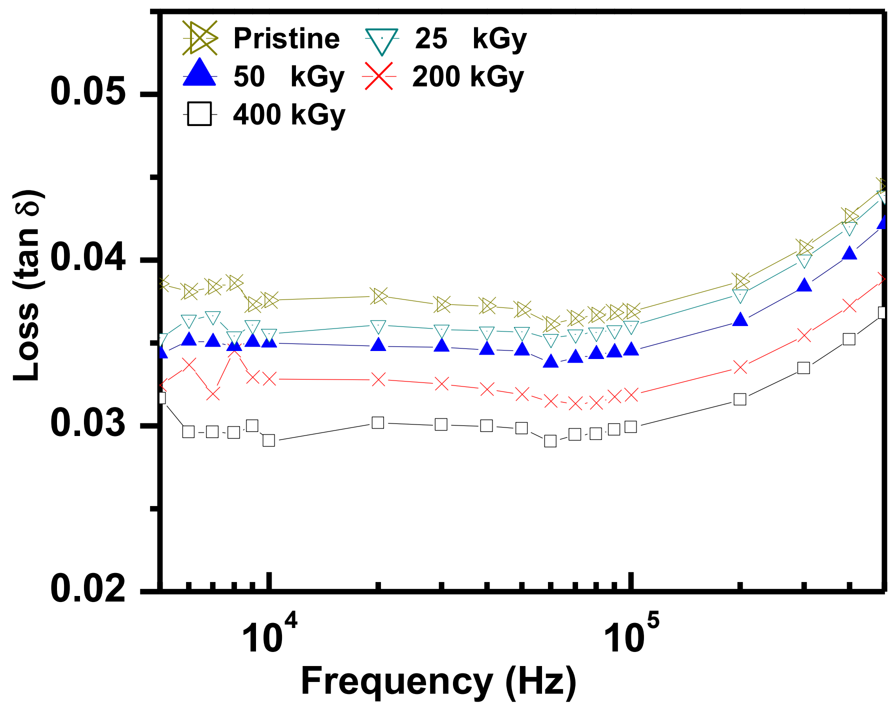


Figure 8.11: Dielectric Loss tangent of PZT varactor with different gamma dose as function of frequency

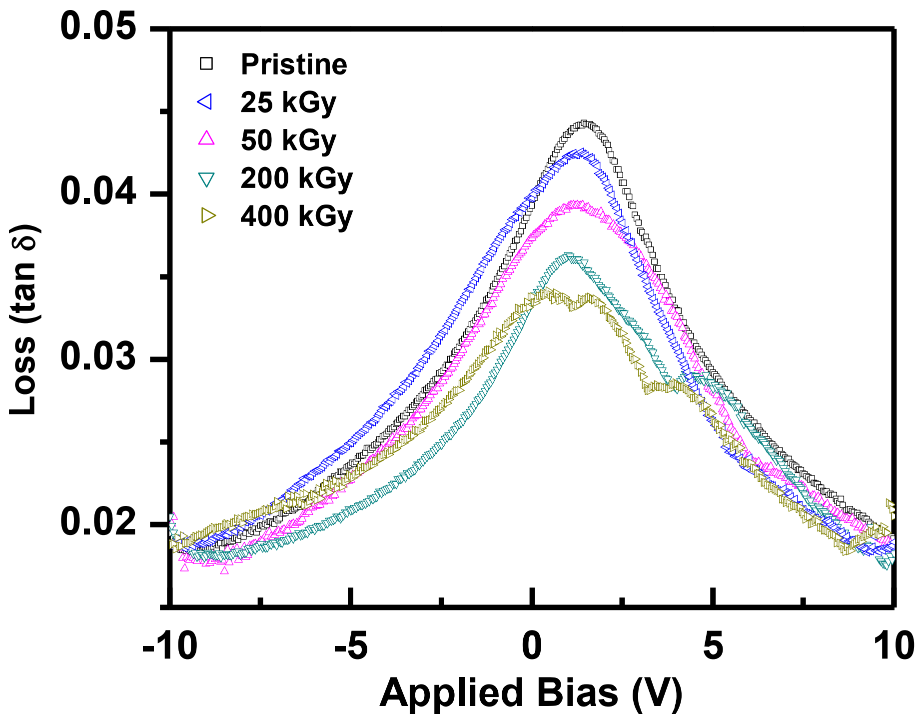


Figure 8.12: Dielectric Loss tangent of PZT varactor with different gamma dose as function of bias voltage at 100 kHz.

However, the decrease in loss tangent after gamma irradiation to higher doses appears due to defects by redistribution of gamma-radiation energy over the sample. The radiation-induced decrement in the maximum capacitance and loss tangent are possibly attributed to an increase in positive trapped charges [Gao *et* al, 2000] and the formation of interface states. The radiation-induced breakage of the weak interface and strain bonds could be the possible reasons for occurrence of these interface states. In addition, gamma irradiated varactor devices also showed an asymmetric characteristic of the C-V, which may be explained by the different interface conditions between top and bottom electrodes. The radiation induced defects and vacancies at the electrode/PZT interface, leading to the trapping of the charge carriers in presence of an applied bias, might be responsible for the observed asymmetric characteristic in the dielectric properties. Moreover, the decrease in dielectric property can also be attributed to the increased strain due to exposure to the gamma irradiation [Nath and Medhi, 2013].

8.4.1 Hysteresis C-V Measurement

Polarization hysteresis (P-E) is considered as a finger print of any ferroelectric (FE) material. However apart from the polarization measurements the capacitance – voltage (C-V) measurements, can also be a potential tool to study the ferroelectric characteristics. C-V behaviour of FE material is known to imitate the slope of the P-E curve but not exactly the slope due to variation in the measurement conditions [Dawber *et al*, 2005]. Hence C-V measurements could be utilized as a tool to study the FE behavior of a material. Hysteresis C-V measurements were carried out as a function of applied voltage for different gamma doses to see the defect contribution in PZT varactor. The hysteresis C-V measurements have been carried out for different gamma doses and shown in Figure 8.13. In the case of FE materials bound charges are produced due to the spatial inhomogeneity of spontaneous polarization and the bound charges gives, a so called depolarization field which opposes the spontaneous polarization. The bound charges can appear at various regions of a sample in reality such as a polar surface, at the encountering of a head to head or a tail to tail domain walls and in the bulk. These bound charges the system breaks up into small regions of uniform polarization called as "domains" to minimize the energy. These domains are FE dipolar domains similar to that of the ferromagnetic spin domains [Lines and Glass, 1979; Shur and Rumyantse, 1997]. It has been proved that the process of polarization reversal of a FE material under an applied electric field is a multistage evolution of the domain structure. The whole phenomenon of domain structure evolution has many stages like i) arising of new domains at the initial stage of applied field, ii) the forward growth of the domains across the sample thickness, iii) sideways growth of the domain walls and iv) coalescence of residual domains and finally reaching a single domain state at the saturation polarization. The whole process explained above is completely reversible in direction from one end of the polarization hysteresis loop to the other. While applying a dc field to a FE thin film, the nucleation and growth of domains is also associated with a domain wall. A domain wall is a boundary wall that differentiates the domains and is generally few lattice constants thick. A 180^o domain wall separates regions of oppositely oriented polarization, while all the others are separated by non 180^o walls. Similar to a grain boundary present in a polycrystalline system the domain walls are at higher energies than that of the interior of the domains. A tetragonal phase mainly contains of 180^o and 90^o domain walls. The different types of domain walls have their own influence in the domain wall motion and domain dynamics when subjected to an external electric field.

The C-V hysteresis curves reveals decrease in charge accumulation with increase gamma doses, indicating significant loss in macroscopic polarization. The hysteresis curve upon irradiation, narrows and shifts downward, indicates a loss of remnant polarization and the presence of an internal local field.

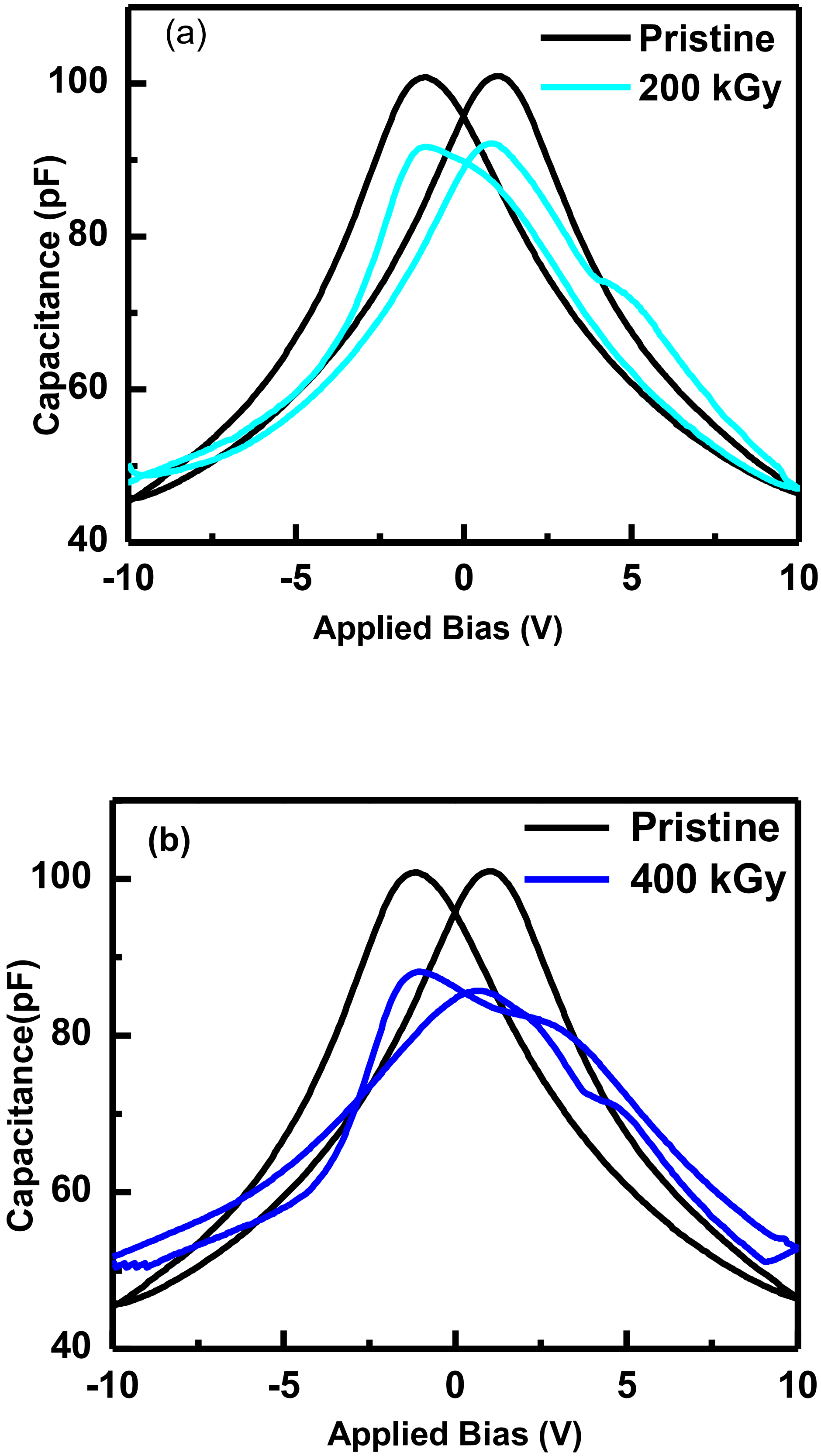


Figure 8.13: C-V hysteresis measurement at 100 kHz as a function of applied bias for gamma irradiated PZT varactor a) 200 kGy, and b) 400 kGy

8.5 RADIATION EFFECTS ON DEVICE TUNABILITY

The dielectric tunability of the devices were calculated from the capacitance–voltage (C–V) characteristics, measured at a frequency of 100 kHz. The applied bias voltage was swept from negative bias voltage (–10 V) to positive bias voltage (+10 V).The tunability (T) is calculated with help of Eq. (8.1).

$$T(\%) = \frac{C(max) - C(V)}{C(max)} \times 100 \qquad (8.1)$$

where C(max) is the measured maximum value of capacitance and C(V) is the capacitance at a certain bias voltage.

It is known that the soft phonon mode is associated to the tunability, which originates from the vibration of Ti and O ions in opposite directions in oxygen octahedra of ABO_3 perovskite lattice. Figure 8.14 shows tunability as a function of applied bias, demonstrating that the tunability of the varactor devices gets strongly affected by the applied electric field. The maximum dielectric tunability is calculated to be 55% with improved figure of merit (FOM= tunability/tanδ) around 28 at 100 kHz at applied bias of 10 V and are comparable with some of the reported data on perovskite structure based parallel plate capacitors [Ha *et al*, 2006; Cole *et al*, 2001; Yu *et al*, 2004]. The advantage of the epitaxial films lies not only in the fact that their defect free microstructure leads to enhancement in-plane oriented polar axis to improve the tunability of the varactor but also impact on intrinsic electrical properties of the device with gamma irradiation induced changes.

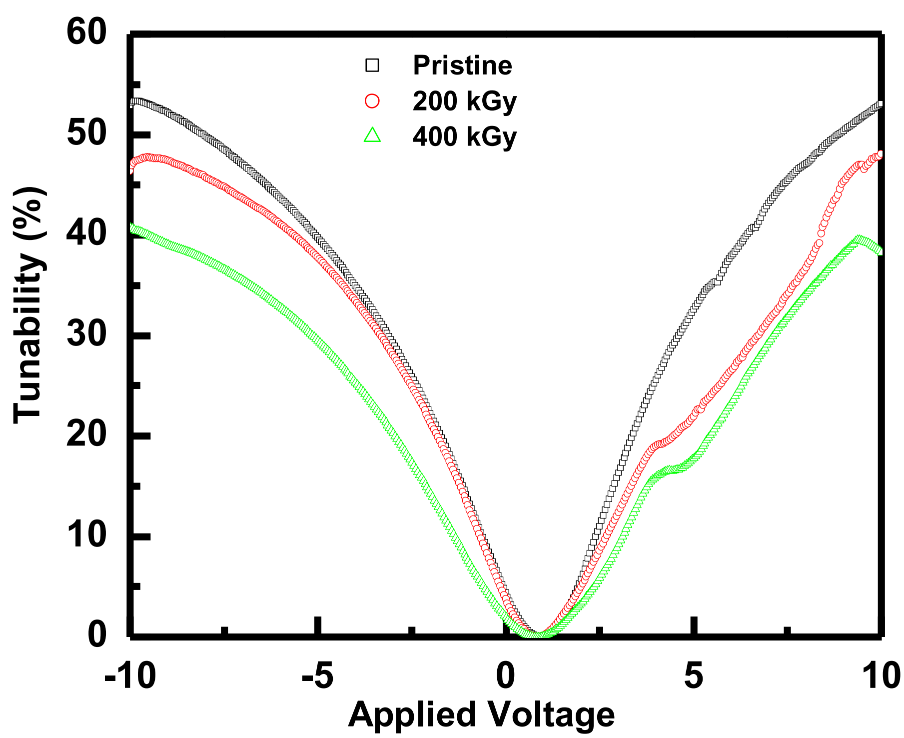


Figure 8.14 Dielectric tunability of the device as a function of applied bias at 100 kHz.

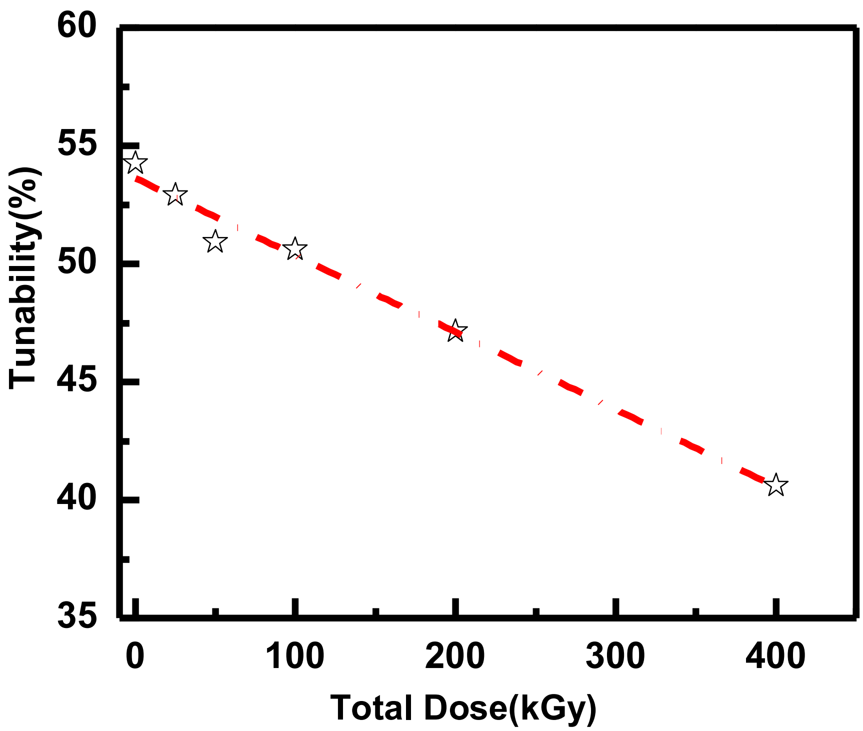


Figure 8.15 Calculated tunability of PZT varactor as a function of total gamma dose at 100 kHz.

Figure 8.15 shows tunability variation of the PZT varactor devices as a function of the gamma dose and about 25% decrease was observed in the dielectric tunablity at the total dose of 400 kGy. Radiation induced local polar regions near the charged defects such as oxygen vacancy [Sirenko *et al*, 2000] might have played significant role on tunability of PZT varactor. The stress in thin films can induce the shrinkage or elongation of crystal lattice and then influence the tunability of films [Hyun and Chark, 2001], where it may lead to decrease the ionic displacement and in-turn lower the tunability of the device [Shao *et al*, 2006].

8.6 LEAKAGE CURRENT

The leakage currents present in the thin films plays a major role in deciding the device performance and the breakage of the dielectric thin films. For example, the presence of defects, grain boundaries and potential barriers at the film-electrode interfaces dominate over the actual bulk conduction. The leakage current analysis has always been essential requirement for tunable device applications so that the flow of charge through the dielectric material should be as low as possible. Leakage current has considered one of the limiting factors for the applicability of a dielectric material in tunable devices. Figure 8.16 and Figure 8.17 demonstrates the leakage current versus applied field of PZT varactors before and after irradiation at two different electrode area varactors. It is clearly seen that the leakage currents show an increase after exposure to higher irradiation levels. Radiation induced trapped charges and structural defects form pinning centers for charges and domain walls at the grain boundaries, leads to reduction of barrier which increase the leakage current significantly.

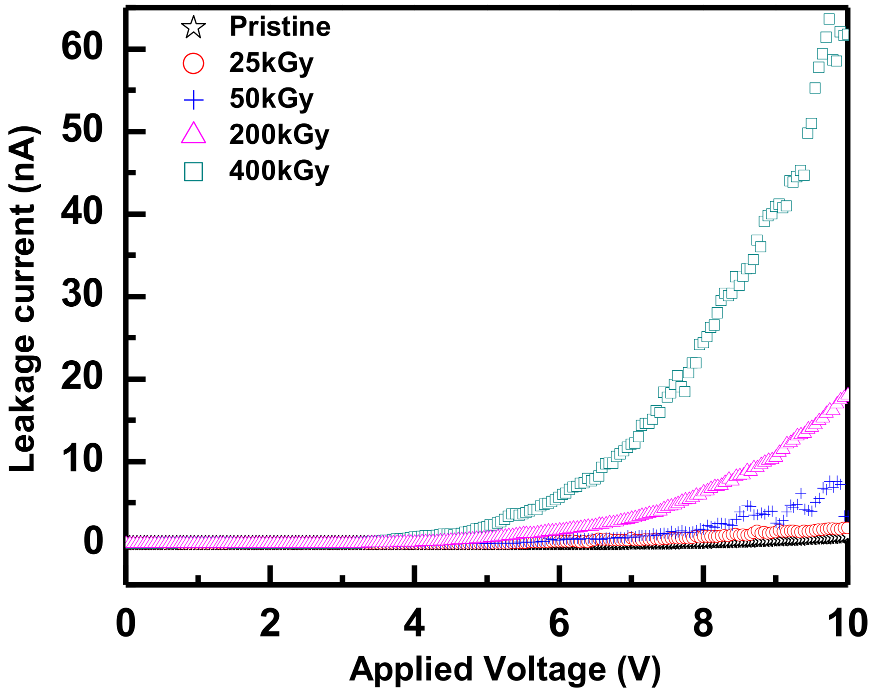


Figure 8.16: Leakage current for PZT varactor before and after gamma irradiation as a function of applied bias for large area electrode.

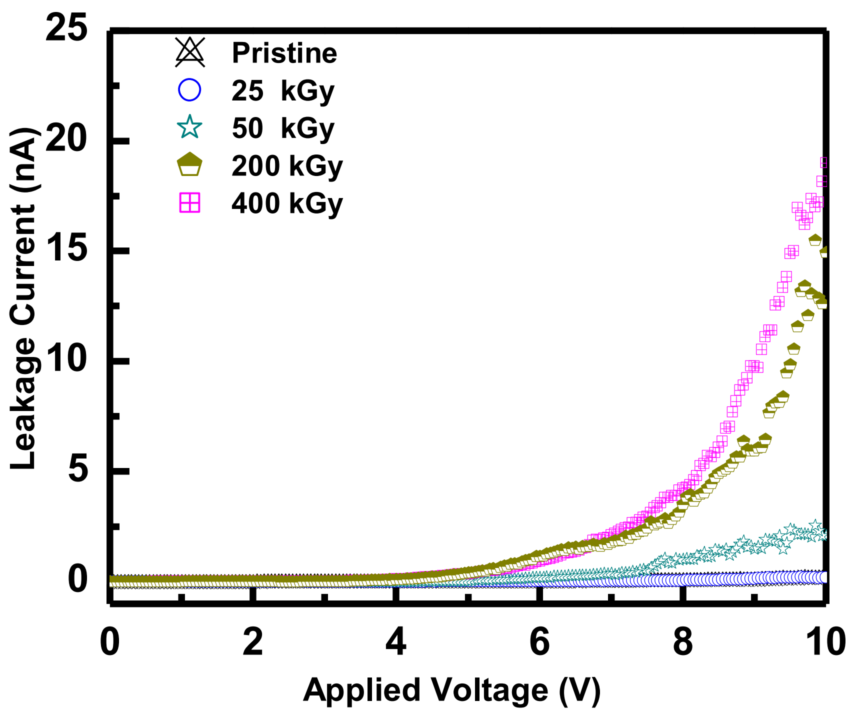


Figure 8.17: Leakage current for PZT varactor before and after gamma irradiation as a function of applied bias for smaller area electrode.

8.7 CONCLUSIONS

The chapter focuses on fabrication of epitaxial Pt/PZT/SRO tunable varactor devices on single crystalline STO (001) substrates in order to study the effect of radiation on the intrinsic dielectric properties of the epitaxial film with minimum interference from the structural defects. In comparison to the polycrystalline films, the epitaxial pristine devices demonstrated higher dielectric tunability and lower loss. The impact of ionizing radiation on electrical properties of the varactor devices was measured as a function of gamma-ray irradiation dose. The C-V curves and loss tangent of the PZT capacitors exhibited significant degradation of dielectric properties with the increasing radiation dose. The C-V curves also exhibited considerable changes after gamma-irradiation in terms of shift in the negative-voltage direction with distortion in the curve shape. The effects of radiation on tunability were also studied as a function of gamma-radiation dose and were found to decreases linearly with increasing radiation dose. This degradation in the electrical properties can be attributed mainly by pinning of the domain walls, caused by radiation-induced defects accumulated at the domain boundaries with increasing dose of PZT varactor. The roles of radiation generated defects, charge carriers leads to significant enhancement of the leakage current with increasing radiation dose. The results achieved would be highly valuable in order to prepare the maintenance schedules for the varactor devices functioning in a radiation environment and also to predict the operating life-time of such devices with integrated ferroelectric films. Synthesis of defect free epitaxial thin film enabled us to investigate the changes in intrinsic properties of the PZT based varactor.