control of emitter structures are needed to fully exploit the potential usage of diamond/carbon field emissions. This paper describes a well-engineered molding process for the fabrication of diamond/carbon field emitter cathodes and devices. Practical modifications involving the sp^2 content, doping, and tip sharpening to further enhance diamond/carbon field emission are discussed.

We also report the development of (a) vertical and (b) lateral diamond field emission devices with excellent field emission characteristics. Vertically self-aligned gated diamond vacuum triodes were fabricated from a silicon-on-insulator substrate. This fabrication technique utilizes conventional silicon micro patterning and etching techniques to define the anode, gate, and cathode. The fabrication has achieved diamond field emitter triodes over practical wafer areas. The field emission of the triode array exhibits transistor characteristics with high dc voltage gain, ~800, and transconductance values. A large ac output voltage of ~100 V peak–peak has been achieved. While in the lateral configuration, diamond vacuum diode was fabricated by a novel diamond patterning technique utilizing oxide patterning and lift-off process. Anode–cathode spacings <2 μm were achieved. The fabricated lateral diamond emitter diode exhibits excellent emission characteristics with a low turn-on voltage of ~5 V and a high emission current of 6 μA, from a four diamond "fingers" configuration. The low turn-on voltage (field ~3 V/μm) and high emission characteristics are excellent for reported lateral field emitter structures.

We also present the development of thermal CVD grown carbon nanotubes (CNTs) for cold cathode applications. Preliminary results demonstrate that CNTs configured as diode field emitters exhibit low turn-on fields and high emission current. The emission current produced by the CNTs tested is more than sufficient for flat panel displays in practical use. The CNT-triode devices have also been fabricated. The emission characteristics show gate-controlled modulation of emission current.

Additional field emission behavior of the diamond and carbon derived field emission devices will be presented. The excellent field emission results in the diode and triode configurations suggest the potential usage of diamond/carbon emitters beyond the conventional vacuum microelectronics to encompass usage such as displays and micro-sensors in MEMS applications and beyond.

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Synchrotron X-ray scattering studies of nano-domains in lead containing perovskite relaxor ferroelectrics

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Synchrotron X-ray scattering studies were applied to single crystals of lead magnesium niobate ferroelectric relaxors Pb $(Mg_{2/3}Nb_{1/3})O_3$ (PMN) with several concentrations of Ti doping corresponding to 0, 6, 10, and 30%. PMN has an ABO_3 perovskite structure, where A sites are occupied by Pb atoms, B sites by a mixture of Nb/Mg/Ti. Atoms on the B sites exhibit some degree of ordering that leads to doubling of the unit cell in the direction perpendicular to {1 1 1} type atomic planes. B sites are surrounded by oxygen octahedra. Experimental evidence exists that Pb and O ions are displaced from their ideal atomic positions. These displacements are not completely random and some degree of correlation exists on the short-range scale.

Synchrotron X-ray scattering techniques were applied to study chemical and displacement ordering from the coherently scattering nanoregions producing two kinds of superlattice reflections called (a) F spots; (b) α spots in literature. These reflections are direct result of doubling of the unit cell in the directions perpendicular to {1 1 1} and {1 1 0} atomic planes, respectively. F and α superlattice reflections were detected only in 0 and 6% Ti doped PMN (PMN–6%PT) single crystals. Radius of correlations in the nanodomains producing F spots is limited to 50 Å and independent of temperature in the 10–800 K interval. Main contribution to the structure factor of the F spots is from chemical ordering on the B sites. However, it was found that correlated displacements contribute to the structure factor of the F spots as well. Existence of the strong asymmetric tails in F spots was detected only in <1 1 1>* reciprocal direction, which suggests existence of the strong distortions in the direction perpendicular to {1 1 1} planes caused by the atomic size effect and/or atomic displacements. Anomalous scattering on the F spots near Pb L_{III} absorption edge provides further evidence that Pb displacements in <1 1 1> direction are correlated on the short-range scale, although the effect on the structure factor was found to be very weak after correcting raw data for known experimental errors and X-ray absorption.

Temperature dependent studies in the range of 10–800 K have shown that the main origin of the α spots in PMN and PMN–6%PT can be attributed to the correlated atomic displacements in {1 1 0} planes. Their integrated intensity exhibits strong temperature dependence below Vogel–Fulcher freezing temperatures T_f, which coincides with the temperature of collapse of the stable remanent polarization. Correlation radius of 30 Å, obtained from the width of these reflections, is independent of chemical composition and temperature below T_f.

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Simulation and ultrasonic study on domain processes in ferroelectrics

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Ferroelectric systems usually contain many different polarization domain states that couple strongly with elastic strain. These domains will co-exist and form complex structures, for example, the 90° twins in a tetragonal ferroelectric system. Theoretically speaking, during the polarization reversal process in a single crystal, domains whose polarization axis is different from that of the applied field could appear. However, textbook mechanism for polarization reversal did not include polarization rotation. It was described as a three-step process: reversed polarization domain nucleation, forward growth, and sideway growth of the reversed polarization state. Optical microscopy cannot see these domain switching processes since the mini-domain mixture will appear uniform to the visible light. In addition, some materials may not even be optically transparent. TEM, on the other hand, will destroy the 3D nature of the ferroelectrics and the boundary constraints often confine the switching process. Recently, we have performed a computer simulation as well as innovative measurements of the domain processes using ultrasonic technique. The simulation results of a 2D four variant model show that the switching path is not as given in the textbook. Instead, two consecutive 90° domain switching occurred. In order to verify this phenomena, we have monitored the polarization reversal process using ultrasound in a single crystal $0.955Pb(Zn_{1/3}Nb_{2/3})O_3$–$0.045PbTiO_3$ which has a rhombohedral 3m symmetry. Direct evidence indicates that the polarization reversal in this system is via a path involves two consecutive domain switching processes, i.e., $0° \rightarrow 71° \rightarrow 180°$, instead of the textbook mechanism of $0° \rightarrow 180°$ domain switching. Our results revealed the intrinsic nature of fatigue in some ferroelectrics in which the reversal process involves large elastic deformation.

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Piezoelectric microactuator arrays using composite PZT thick films

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Preparing crack-free lead zirconate titanate (PZT) films with thickness up to 50 μm is still a challenge for ferroelectric MEMS applications. In this paper, a modified 0–3 composite route for thick film preparation has been reported. The film properties such as microstructure, crystallinity, ferroelectric, and dielectric properties have been optimized in terms of the variable processing parameters such as concentration of the sol–gel solution, powder/solution mass ratio, vehicle content, annealing temperature, powder size, and cold isostatic pressing. Within the optimum processing conditions, the thickness of crack-free PZT films on the platinum-coated silicon substrates can be easily adjusted between 1 and 50 μm. PZT/silicon diaphragm array with such composite thick films has been fabricated by using silicon micromachining. The electromechanical properties of the diaphragms have also been evaluated and presented.

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Novel high-pressure crystallization process for the preparation of electronic ceramic thin films at low temperatures

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The research and development of thin-film technology for electronic ceramics has been stimulated by the necessity for producing microelectronic devices and systems having compact size, light weight, and low power consumption. Electronic ceramic thin films are being extensively applied in various types of electronic and optical devices such as microelectromechanical systems, dielectric capacitors, sensors, and electro-optic displays.

Because the electronic ceramic thin films are difficult to be crystallized, either in situ heating or post-annealing high temperatures for complete crystallization is necessary. In order to reduce the crystallization temperature of electronic ceramic thin films, a novel high-pressure crystallization (HPC) process has been developed. The crystallization temperatures of ceramic thin films (PZT and Ta_2O_5) were significantly decreased to lower than 400 °C. It was found that the crystallization process of ceramic thin films was markedly enhanced by high-pressure processing. In addition, the interactions between ceramic films and substrates were substantially reduced. The formation process and development of the microstructure were investigated by XRD, GIXD, SEM, and SIMS. The prepared thin films were demonstrated to exhibit high dielectric constants and good electric properties. This HPC approach for synthesizing electronic ceramic thin films can effectively reduce the thermal budget and alleviate the malfunctions resulting from pronounced interdiffusion