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A new poling method for piezoelectric ceramics with thick film

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Abstract

The poling process plays an important role in the interaction with the crystal structure in a number of ways to obtain ferroelectricity and piezoelectricity. However, many factors influence the effectiveness of poling process. In the conventional poling process, electric field is applied to the ceramics via the metal electrode. The drawback of conventional poling method is the occasional occurrence of fracture and crack due to subjection to high electric voltage. In this study, a new poling method by using ITO (Indium Tin Oxide) glass for piezoelectric ceramics with thick film is proposed. The constraint of applying high electric field has been overcome and is verified with the use of energy level concept. As compared to conventional method, using ITO for poling will preserve better performance via various experimental testing.

Keywords: Piezoelectric ceramics; Thick film; Poling; ITO

1. Introduction

The piezoelectric ceramic material is popularly used in many applications due to its intrinsic electro-elastic interaction through piezoelectricity or ferroelectricity effects. The combination of piezoelectric material and thin film technology attracts quite a few of research works. In this decade, thick film of piezoelectric material is used to make miscellaneous actuators or sensors such as motor, vibrator, surface acoustic wave sensor, torque sensor, and pyroelectric detector.[1–3] Other advantages of ferroelectric ceramics are chemically and mechanically stable at room temperature, and relatively easy to prepare in the form of polycrystalline samples.[4] Piezoelectric materials generate an electrical potential in response to an applied stress. Note that, all ferroelectrics are piezoelectric but not all piezoelectric are ferroelectric. Also some ferroelectrics show a very small piezoelectric effect. As known, crystalline of the piezoelectric material influences the piezoelectricity and ferroelectricity. A dipole is generated by a shift of charge inside the crystal lattice or a distortion of the crystal. Therefore, poling can interact with crystal in numerous ways, and determines the quality and function of piezoelectricity as well as ferroelectricity. In the conventional poling process, an electric field is applied to the ceramic via the metal electrode that generates rotating of dipole moment in the direction of the applied electric field. However, defects such as fracture, crack, dislocation are the problems exist in conventional poling under high applied electric field.[5,6] Quite a few of research works have been investigated on the cause and effect between electric field and fracture. To name a few, Suo et al. connected the fracture concept of energy release rate and stress intensity factor to piezoelectric ceramics by implementing another factor of electrical energy release rate and field intensity.[7,8] Park et al. investigated similar research by applying electric field parallel and perpendicular to the crack.[9] It was concluded that the release rate of mechanical strain energy defined by the crack closure integral is a suitable parameter for a fracture criterion of piezoelectric ceramics. Gao et al. developed a strip electrical saturation model to explain the fracture effect resultant from applied electric field.[10] Ru used strip saturation model to study the conducting crack with limited electrical polarization.[11] Yang et al. inspected the shielding effect by the switch wake of ferroelectric domain to ascertain the cause of crack.[12] Suo explored different conducting path and found basic cracking mechanism while the switching zone was localized around the end of a conducting electrode.[13] Electric field at the tip of conducting layer is non-homogenous and much higher in magnitude than the nominal applied electric field. Lynch et al. observed the dielectric breakdown happened inside the crack.[14] Zhang et al. found local partial electric discharge would make an impermeable crack and conduct electricity as well as change

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Nomenclature

E_A	acceptor level
E_C	conduction band
E_{CN}	conduction band ITO
E_{CP}	conduction band PZT
E_D	donor level
E_F	Fermi level
E_{FM}	Fermi level metal
E_{FN}	Fermi level ITO
E_{FP}	Fermi level PZT
E_G	energy gap
E_{GN}	energy gap ITO
E_{GP}	energy gap PZT
E_V	valence band
E_{VN}	valence band ITO
E_{VP}	valence band PZT
ID	inside diameter of PZT sample
OD	outside diameter of PZT sample
V_{biN}	built-in potential barrier ITO
V_{biP}	built-in potential barrier PZT
W_M	work function metal
W_N	work function ITO
W_P	work function PZT
X_N	electron affinity ITO
X_P	electron affinity PZT
ΔE_C	conduction level difference
ΔE_F	Fermi level difference
ΔE_V	valence level difference
ϕ_B	potential barrier (Schottky barrier)

the failure behavior of piezoelectric materials.[15] All the above studies imply that crack occurs due to high electric field in the process of poling. Crack appears will lead to electric breakdown and affect polarization. Although an attempt is to limit the electric field in poling in order to avoid from cracking, however, low piezoelectric constant is obtained. Hence, applying high electric field to preserve good piezoelectricity without cracking phenomenon is demanding. In this article, a new poling method of using Indium Tin Oxide (ITO) glass is proposed, which will achieve the target without the disadvantaged problems while using conventional poling method. ITO coated glass is widely used for a number of applications due to its electrical conductivity and optical transparency.[16,17] ITO provides small surface roughness with size of crystallites of 10–15 nm, which are homogeneous and relatively flat. With small electrical resistance of ITO, limited current is allowed to flow through the ceramics. ITO is an ideal candidate of optimum charge carrier transport for having high energy band.[18] In our previous work,[19,20] ITO glass was used for poling the polymer material. Higher electric field can be applied during polarization so that more dipole is oriented. As a result, higher piezoelectric constant is obtained. The conventional poling method utilizes metal electrode deposited onto surface of piezoelectric ceramics that would easily produce crack/microcrack, and cause electrical breakdown as well as disturb polarization. Different from using metal electrode, ITO is deposited onto a soda lime float glass and used as a conductor to transmit electric field. Sandwich structure constructed with *ITO glass – Piezoceramics – ITO glass* is employed for poling. With high energy band, ITO is able to obtain high peak velocities. Therefore, high electron transfer interface between the ITO and piezoelectric ceramics is formed, that allows for applying higher electric field.

2. Energy band concept

Poling condition is required to obtain optimal piezoelectric characteristics; however, it significantly varies for different materials. Generally, the purpose of poling process is to induce maximum degree of domain alignment by implementing lowest electric field at temperature as close as possible to room temperature. Electrode is usually coated onto the surface of piezoelectric ceramic to transmit electric field so as to rotate domain orientation. Quality of piezoelectric constant is strongly dependent material aspects and the interface between the electrodes of piezoelectric material. Phenomena of conductivity can be described by the concentration and the mobility of charge carrier. If the atoms are far away from each other, the interaction may be disregarded, and the electrons will have the same energy levels. Conversely, if the atoms close each other and form crystal, the electron levels are split into mutual interaction of electrons. Consider applying electric field to crystal for polarization for example, can generate negative charge with respect to positive one. This circumstance means the valence band is completely filled energy of valence electron as depicted in Fig. 1.[21]

Fig. 1 shows the band model of various types of materials where the shaded areas represent filling of energy band, and E_G is energy gap.[21] The higher energy electrons go beyond the valence band as an effect of applying electric field. So they are capable of moving through the crystal and making conduction. Unlike the condition shown in Fig. 1(a), good electrical conductivity of many metals is achieved results from overlapping of the conduction and valence bands since there is a sufficiently large number of electrons can move shown in Fig. 1(b). The band model of ceramics without electron capability of moving through the crystal is an insulator shown in Fig. 1(c). Band model of semiconductor has small energy gap expressed by $E_G < 2$ eV, so the electrons can move while encountered with electric field. If a semiconductor with electron holes in the valence band is placed in the electric field, electrons drifting in between the conduction band and valence band may happen. Therefore, jump of such an electron to electron hole is possible. Energy level of electron in the energy gap is illustrated in Fig. 2. Fermi level is defined as the highest occupied molecular orbital in the valence band at 0 K, in which many states are available to accept electron. For semiconductor, the Fermi level is located in the band gap since the valence and conduction band is separate. The impurity atoms give up electrons to the conduction band is called donors, and such a semiconductor is called *n*-type impurity semiconductor since the charge carrier is of negatively charged electrons drifting in the conduction band. In donor-type of energy gap, the Fermi level E_F is close to the lower edge of conduction band E_C,