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Multi-breakdown model for explaining the formation and growth of black spots in PZT capacitor under DC bias

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ABSTRACT

Lead zirconate titanate (PZT) is widely used in various electro-mechanical devices because of its piezoelectric function. In some of its applications, the piezo ceramic will be subjected to a DC bias. The applied DC bias will stress the PZT ceramic and can undergo an electrical degradation process. This electrical degradation process demonstrates itself as resistance decreases and leakage current increases. Therefore, the electrical degradation phenomenon can severely impact on device performance and reliability. It has been found that, accompany this electrical breakdown process, black spots will appear in the ceramic body. In this paper, the formation and growth of the black spots in a PZT capacitor under DC bias is investigated. The black spot area is further characterized with various analytical methods. Based on previous research, a multi-breakdown model is proposed for explaining the mechanism of black spot growth.

1. Introduction

Lead zirconate titanate (PZT) ceramics are widely used in applications such as capacitors and actuators because of its good performance and low cost. Normally, in these applications, the PZT ceramics are subjected to a high DC bias. Electrical degradation phenomenon is found if the applied DC bias is maintained for an adequate duration [1]. A higher DC bias or higher humidity of the test environment can accelerate this electrical degradation process. Therefore, in the applications of the PZT ceramics, its resistance to harsh operating environments and high DC bias has become a main topic of research and has been frequently investigated.

An electrical degradation mechanism has been proposed [2] by investigating PZT samples with silver electrodes. In this case, it has been suggested that the silver ionizes at the anode and migrates towards the cathode through the grain boundary due to the applied high voltage. Then these silver ions reduce to metallic Ag on reaching the anode leading to the decrease of the isolation resistance. Molten metal occurs as a result of the heat released from the increased current flow.

Lipscomb [3] and Zheng [4,5] proposed a mechanism of the electrical degradation process by investigating PZT samples with nickel, silver and gold electrodes. In this mechanism, it is suggested that the nickel or silver anode reacts with water vapour and loses electrons at the anode producing these metallic ions. These metallic ions migrate to the cathode forming dendrite structures (or filaments) and build up to the anode. When the metal filaments reach a certain distance to the anode, the concentration of the defects exceeds a critical value causing the formation of conductive pathways and the onset of electrical breakdown [6]. The electrical breakdown can collapse due to the energy concentrated in the small breakdown area causing joule heating (burn-out). The onset of electrical breakdown (producing a current pathway) and its collapse (the cessation of the pathway) process produces current fluctuations, which have been captured [4]. These current fluctuations show shark-fin or square profiles which have high current intensities (up to 100 μA). Herzberger et al. have confirmed the existence of dendrites, which contains the electrode element and influence the leakage current [7].

Discoloured stops or regions are found accompanying the electrical degradation process of the PZT ceramics [3]. These discoloured regions can be observed on the anode surface of the tested ceramics by the viewing with a brightfield macroscopy (BFM). These discoloured regions were not present on the control samples or on the cathode surface of the test samples and are suggested to grow with time under stressed conditions.

However, the micro mechanism of onset and growth of the appearance of these discoloured regions have not been discussed in

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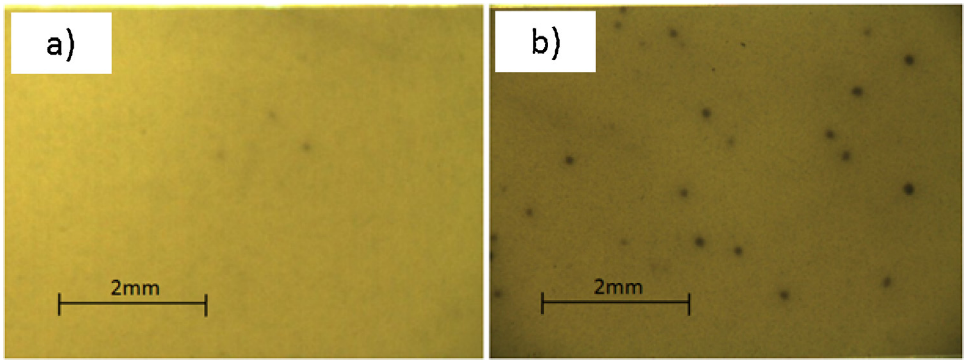

Fig. 1. Images of sample A (a) and B (b) from anode side after removing electrodes under inverted optical microscope.

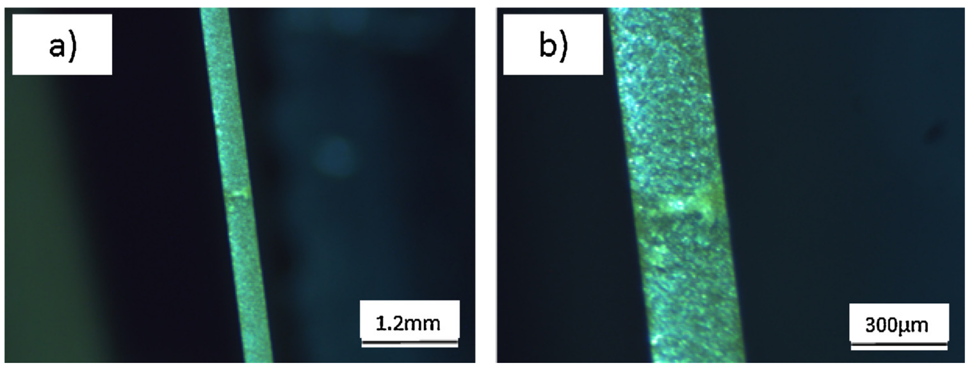

Fig. 2. Images of the cross-section of black spot area under optical microscope (right side is anode side).

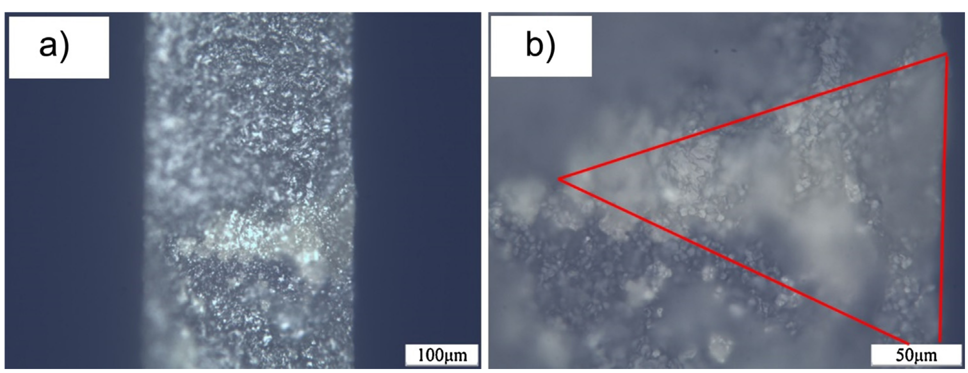

Fig. 3. Images of the cross-section of black spot area under metallurgical microscope (right side is anode side).

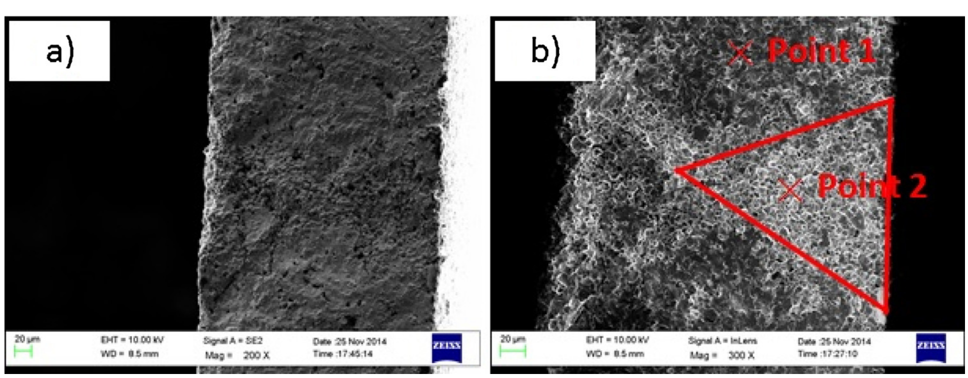

Fig. 4. SEM photos of the cross-section of black spot under Inlens (a) or SE2 detectors (b) (right side is anode side).

any detail before. These discoloured regions are called black spots in this paper and the mechanism of the appearance and growth will be discussed in detail by investigating the leakage current through the PZT samples under a harsh environment and high DC bias. Based on