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Multifunctional tunable and piezoelectric $Ba_{1-x}Ca_xTi_{1-y}Zr_yO_3$ thin film capacitors for energy efficiency and harvesting

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Abstract

Multifunctional materials exhibiting both variable permittivity under electric field and large piezoelectric coefficients can be used in microelectronic applications for energy efficiency as an active impedance matching as well as for vibration energy harvesting. We propose here the exploration of the ternary phase diagram $BaTiO_3$-$BaZrO_3$-$CaTiO_3$ (BCTZ) through the (piezo) electrical characterization of thousands of thin film capacitors deposited using combinatorial pulsed laser deposition (CPLD).

Key words

Tunable capacitor, piezoelectric material, impedance matching, vibration energy harvesting

1. Introduction

Tunable ferroelectric capacitors, which exhibit a decrease of the dielectric permittivity (ε) under electric field, are widely used in electronics for RF tunable applications (e.g. antenna impedance matching). Current devices use barium strontium titanate (BST) as the tunable dielectric and the need for performance improvement of the tunable element is the key for device improvement. For this purpose, we chose to investigate the $BaTiO_3$-$CaTiO_3$-$BaZrO_3$ ternary phase diagram. Indeed, it has been recently shown for (1-x)$BaTi_{0.8}Zr_{0.2}O_3$-x$Ba_{0.7}Ca_{0.3}TiO_3$ (BCTZ) ceramics[1] an increase in dielectric, piezoelectric and ferroelectric properties due to the presence of a morphotropic phase boundary (MPB) for x=0.5 that could lead to an increased tunability.

More recently, thin films of BCTZ on $Pt/TiO_2/SiO_2/Si$ substrates, with composition at the MPB, were deposited via pulsed laser deposition (PLD), and shown a tuning ratio (defined as the ratio of the maximum of permittivity by the permittivity under an electric field) of about 5/1 under a field of around 300kV/cm [2].

2. Development

We report here on libraries of BCTZ thin films deposited on $IrO_2/SiO_2/Si$ substrates using CPLD and allowing for gradients of composition on one sample [3]. A series of height samples were synthesized, each corresponding to one line in the ternary phase diagram and containing 480 capacitors across the composition spread (40 different compositions and 12 capacitors per composition) for statistical analysis. The dielectric properties were investigated on a total of about 3800 capacitors by impedance spectroscopy while the effective piezoelectric coefficient d_{33} were evaluated using dual beam laser interferometer on a quarter of this population. We show that high tunability (>60%) can be obtained under an electric field of 250kV/cm, that the role of zirconium and calcium for dielectric loss reduction and tunability are intricated and not monotonic but also that the lowest dielectric losses and maximum tunabilities are not necessarily correlated. Composition with an effective piezoelectric coefficient d_{33} of 35 pm/V, close to the one obtained for PZT thin films of the same thickness (48 pm/V @ 130 nm) [4], were identified.

3. Conclusion

We have shown that CPLD is a powerful tool to perform fine and continuous scans of the $BaTiO_3$-$CaTiO_3$-$BaZrO_3$ ternary phase diagram in order to identify the best material compromise depending on the needs (low V, high tunability, low dielectric losses, figure of merit, high d_{33}...) for tunable capacitors in impedance matching circuitry and / or vibration energy harvesting through piezoelectric effect.

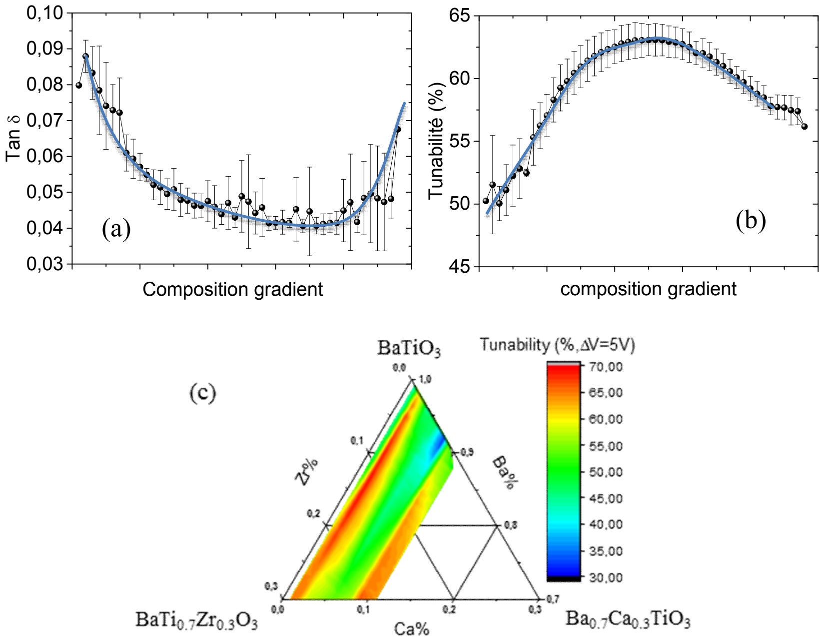

Fig. 1: Tan δ (a) and tunability (b) as a function a composition for a BCTZ library. (c) Contour maps showing the tunability as a function of compositions.

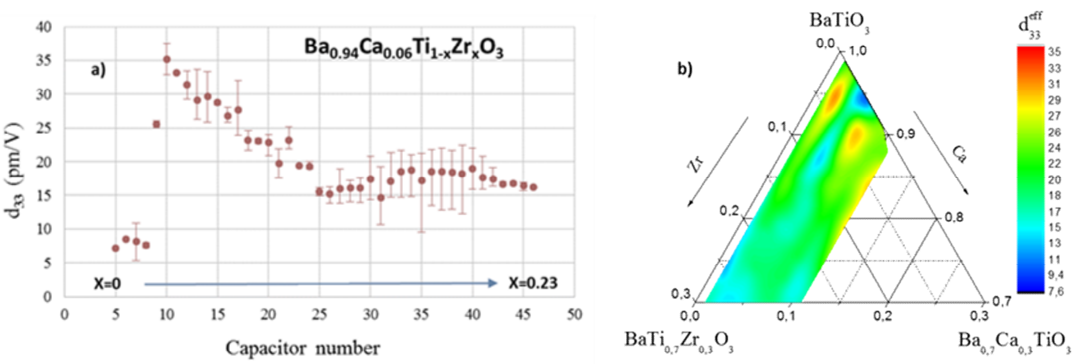

Fig. 2: Effective d_{33} as a function a composition for a BCTZ library (a). (b) Contour maps showing the effective d33 as a function of compositions.

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