Refined characterization up to millimeter waves of ferroelectric KTN thin film for efficient integrated tunable devices.

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During the past decades, applications using ferroelectric materials as tunable devices have grown drastically. For microwave devices, the need in terms of tunability, miniaturization and integration are satisfied by using high permittivity ferroelectric thin films with a good voltage control of their dielectric constant. One good candidate appears to be $BaSrTiO_3$ (BST) based composition, and is one of the most studied. However, investigations on other compositions have an interest to consider heterostructures, for instance, to improve tunability or to reduce dielectric losses. As device performances are directly linked with the dielectric properties of the film, it is of prime importance to have in a first time the knowledge of its complex permittivity in a wide frequency range.

A $KTa_{0.65}Nb_{0.35}O_3$ thin film with a 400nm thickness has been deposited by Pulsed Laser Deposition (PLD) on a 1x1x0.05 cm^3 MgO substrate. The deposition has been made under a 700°C temperature, with an oxygen pressure of 0.3 mbar and with a target enriched in potassium. XRD analysis shows a perovskite-phase, without any secondary phase, and with a (100) orientation. Complementary analysis (XRD φ-scans) enables to determine an epitaxial growth.

In order to extract the complex permittivity of the deposited KTN layer, specific metallization patterns were processed on the film and de-embedding techniques were used to eliminate parasitic effects due to propagation in the access lines.

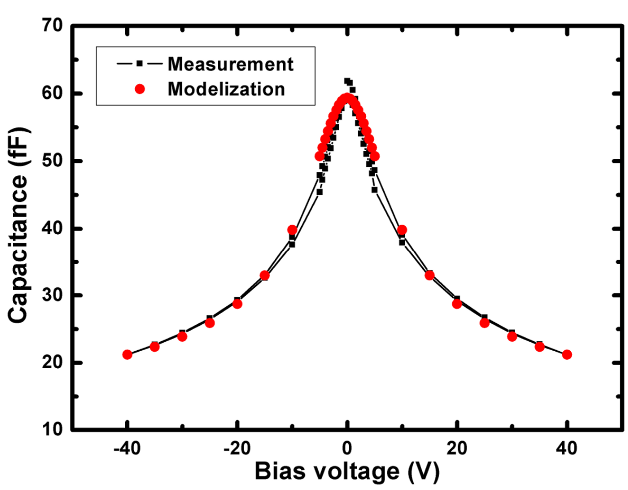

Fig. 1. Interdigitated Capacitance versus bias voltage measured at 30 GHz (T=300 K). Measurements are in black squares symbols and model in red circles.

Tunability of the KTN thin film was extracted by using InterDigitated Capacitors (IDC). The space between fingers of this device is 1 µm. By applying a maximum bias voltage of 40 Volts (which correspond of a 400 kV/cm static field), we obtain a contrast ration of 64% at the frequency of 30 GHz as shown in Fig. 1. This extraction takes in account the variations due to the tunable part of the IDC, but also of a parasitic capacitance C_p which can be retrieved by a model given in ref. [1]. Fig. 1 shows a good fit obtained by taking a C_p value of 9 fF. Unfortunately, from a device point of view, the tunability of this parasitic capacitance is negligible with respect of the IDC ones. So, to have the tunability of the material (and not the device), we can shift down the C(V) curve of 9 fF and it results a contrast ratio value of 75%. This huge value of tunability is an undeniable asset of this KTN thin film.

At last, by using CoPlanar Waveguides (CPW) transmission lines, it is possible to extract the complex permittivity of the layer.

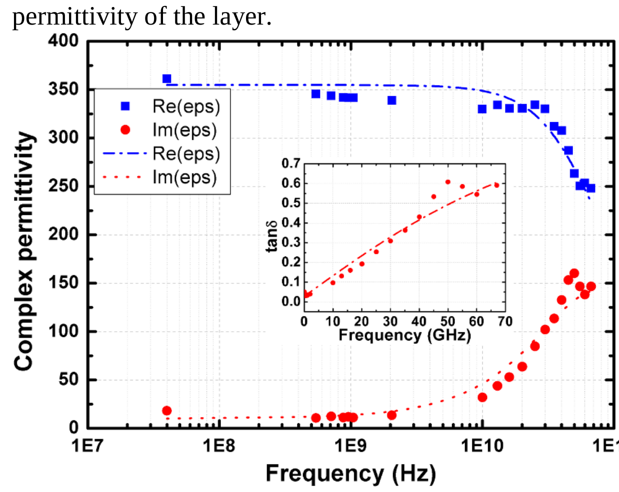

Fig. 2. Measurements (symbols) and modeling (lines) of the KTN thin film complex permittivity. The inset shows its loss tangent.

By applying a specific extraction procedure given in ref. [2], we obtained the complex permittivity variations up to 67 GHz of the KTN ferroelectric film. From a physical point of view, it can be shown that the permittivity dispersion can be treated by a quasi-Debye model due to electromagnetic waves interactions with the local soft-phonon modes. A good fit is obtained by using a Cole-Davidson model (which presents an excess of loss in high frequencies):

$$\varepsilon^*(\omega) = \varepsilon'_\infty + \frac{\varepsilon_s^* - \varepsilon'_\infty}{(1 + j\omega\tau)^\beta} \quad (1)$$

where ε'_∞ and ε^*_s are respectively the high and low frequency permittivity values and τ is the distribution center of relaxation time. The β exponent, which makes a deviation of the pure Debye model when different of 1, indicates the variance of this distribution.

Let us mention that the value of tanδ (plotted in inset of Fig. 2), which appears to be high, permits to investigate for applications that operate under 10 GHz. Above this frequency, the use of this KTN material requires an improvement of its physical characteristics to ensure a better high frequencies behavior.

References:

[1] T. Lacrevaz & al., “Wide band frequency and in situ characterization of high permittivity insulators (High-K) for H.F. integrated passives,” *Microelectronic Engineering*, vol. 83, pp. 2184-2188, 2006.

[2] D. R. Chase & al. “Modeling the capacitive nonlinearity in thin-film BST varactors,” *IEEE Trans. Microwave Theory & Tech.*, vol. 53, no. 10, pp. 3215-3220, 2005.