Strain Effects in FE Films

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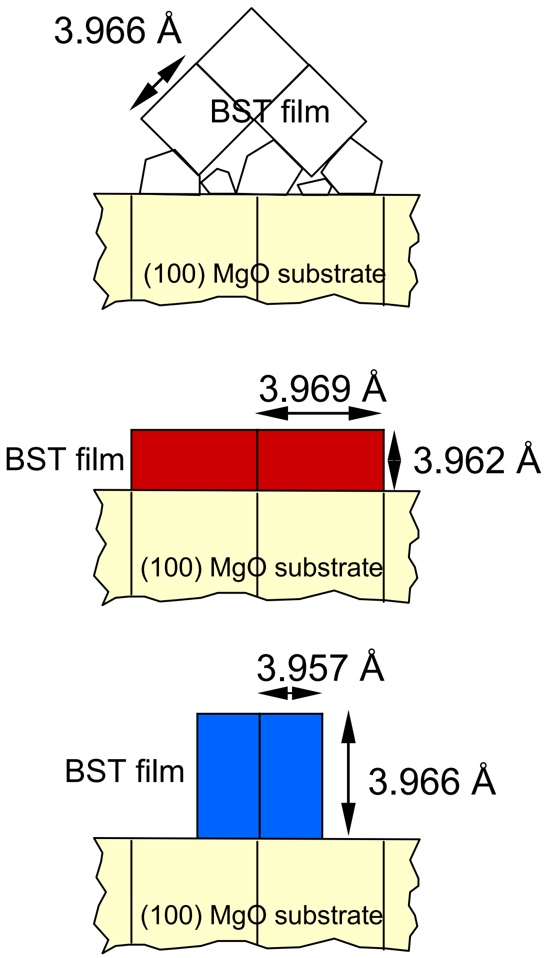
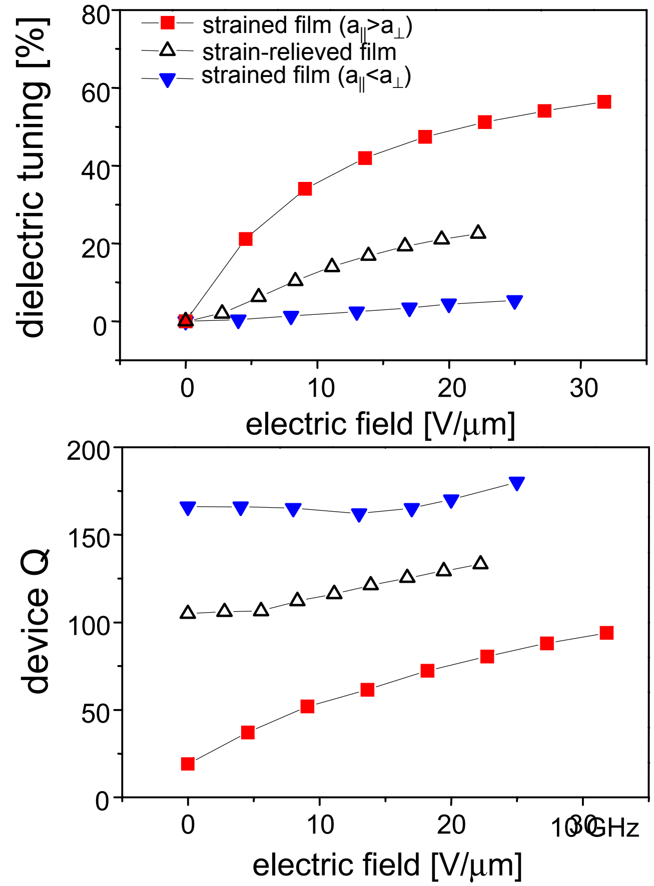
- Ferroelectric, FE, films with DC electric field-dependent dielectric constants, such as $Ba_{1-x}Sr_xTiO_3$ (BST, $0 \leq x \leq 1$), are currently being developed for low-loss, highly tunable dielectric microwave devices.

- We have observed that epitaxially grown $Ba_{1-x}Sr_xTiO_3$ (BST, $0.4 \leq x \leq 1$) films are distorted from the normal cubic symmetry of bulk material of the same composition at room temperature.

- This structural distortion is caused by film strain and has a strong impact on the microwave dielectric properties.

Strained and Strain-relieved (Ba,Sr)TiO_3 films

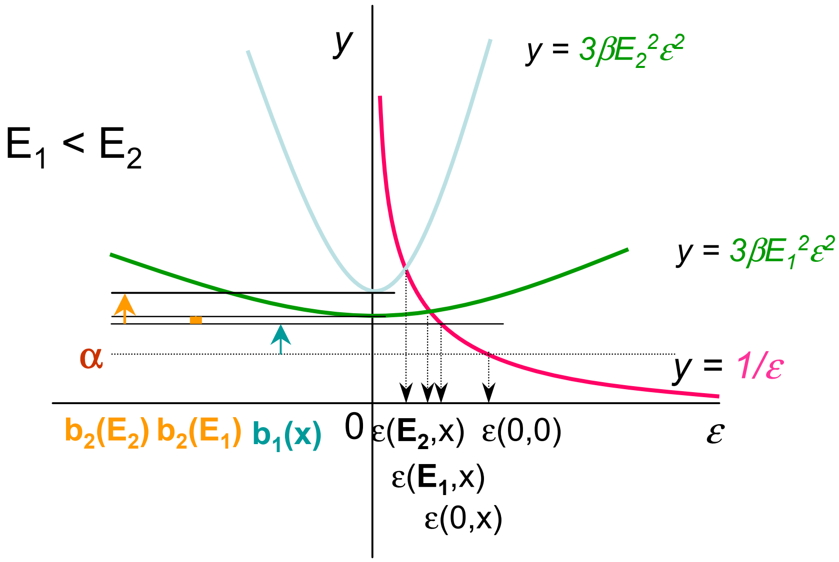


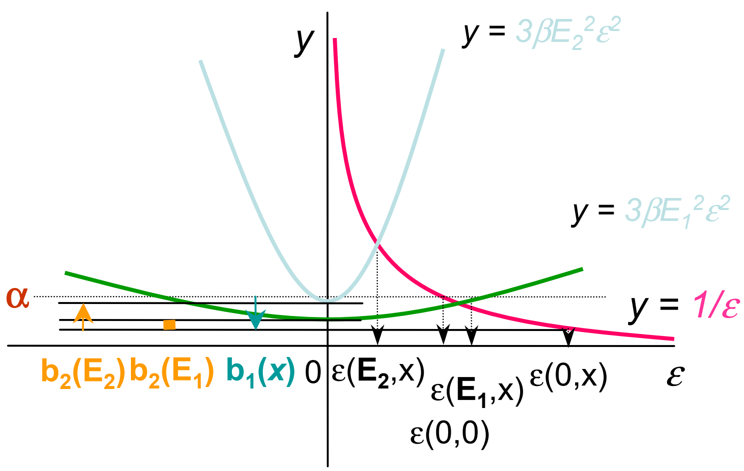


Room Temperature Dielectric tuning and Device Q at 10 GHz

Strain-relieved films show a high Q (>100) with a usable tuning (20% at 20V/μm)

Theoretical analysis of strain effects





- Compressive strain smaller dielectric constant and smaller tuning

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Total strain components:

$x_i = x_{el} + x_p + x_{es}$

$= s_{ij} X_j + d_{ki} E_k + R_{i\,kl} E_k E_l$ (i, j = 1,…,6; k, l= 1,2,3)

$$\partial E/\partial P = 1/\varepsilon = \alpha + 3\beta E^2\varepsilon^2 + b_1(x_{el}) + b_2(E)$$

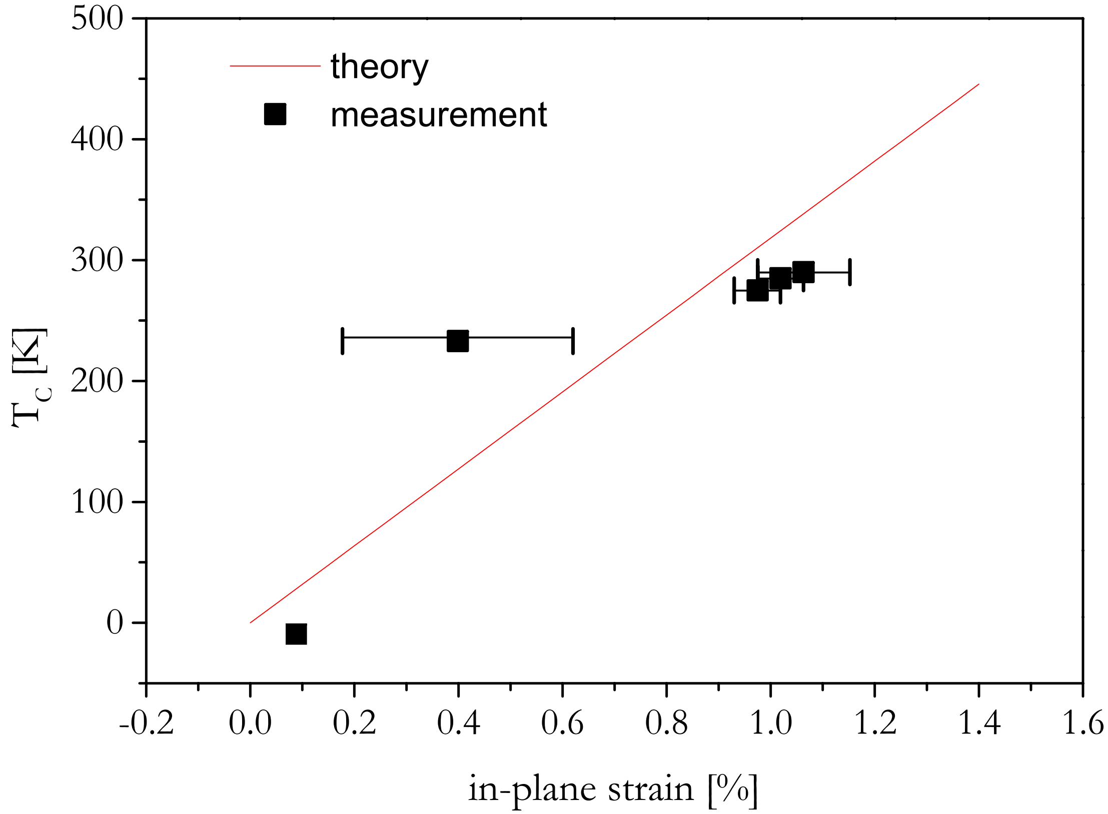
where $b_1(x_{el}) = 2G_{11}x_{el} + 2G_{12}\{1 - 2(c_{12}/c_{11})\}x_{el}$ and $b_2(E) = 2G_{11}R_{11}E^2 + 2G_{12}\{1- 2(c_{12}/c_{11})\}R_{11}E^2$

elastic strain components:

$x_{el} = x_{lattice} + x_{thermal} + x_{phase} + x_{defect}$

- Tensional strain larger dielectric constant and larger tuning

Theoretical phase transition as a function of film strain



$$\frac{\partial E}{\partial P} = \alpha + 2G_{11}x_1 + 2G_{12}(x_2 + x_3) = \frac{(T - T_C)}{C}$$

where $x_3 = -2\frac{c_{12}}{c_{11}}x_1$ and $x_1 = x_2$