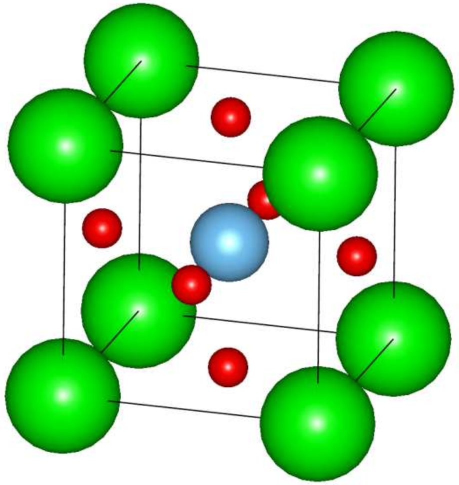
Dielectric and Structural Characterization of Codoped $Ba_{0,6}Sr_{0,4}TiO_3$ Thin Films for Tunable Passive Microwave Applications

Florian Stemme

Electronic Materials and Applications 2012, Orlando, Florida

Institute for Applied Materials – Material Process Technology



Outline

- Introduction
- Iron acceptor doping
  → Processing of iron doped BST thin films

  → Influence of iron doping on microwave properties
- Iron/Fluorine co-doping
  → Processing of iron/fluorine co-doped BST thin films

  → Influence of iron/fluorine doping on microwave properties
- Summary

Introduction

Design and development of materials/components for tunable, passive microwave applications

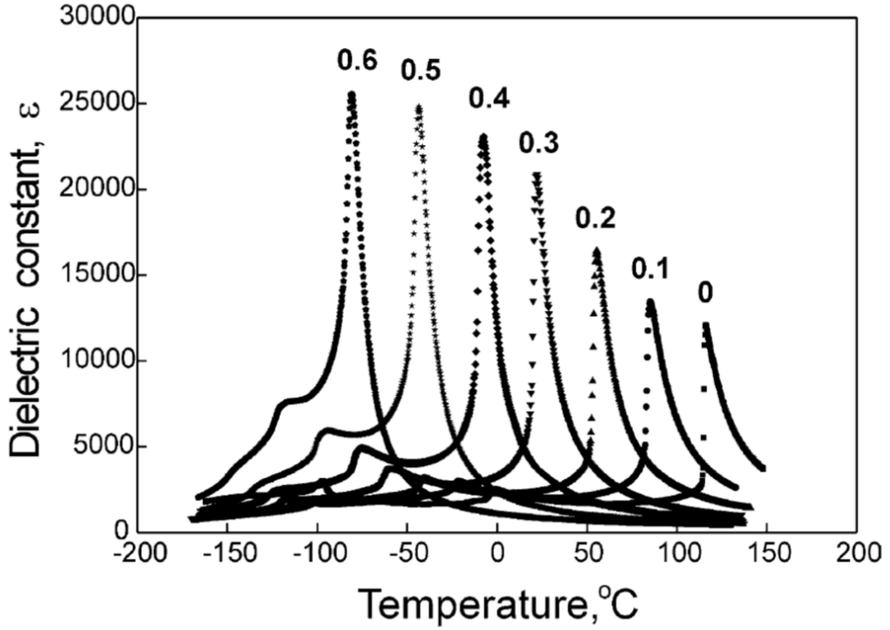
- **Technologies to realize these components**
  - Semiconductor Technology
  - Micro-Electro-Mechanical Systems (MEMS)
  - Tunable Dielectrics

- **Requirements for materials for tunable microwave applications**
  - high tunability
  - low dielectric loss
  - low power consumption

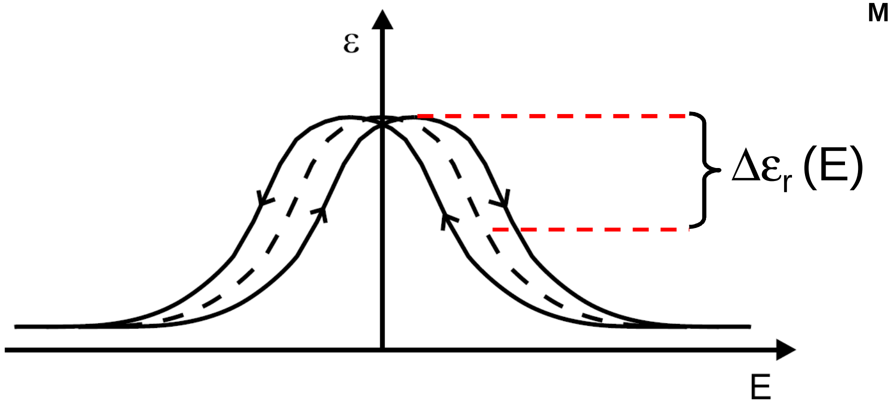
⇨ **(Ba,Sr)TiO_3 possesses high potential for the desired microwave applications**

Introduction

- **$Ba_{0.6}Sr_{0,4}TiO_3$**
  - Permittivity of the material depends on the applied electric field
    → Tunability τ
  - Displacement of the Ti^{4+} Ion due to the electric field

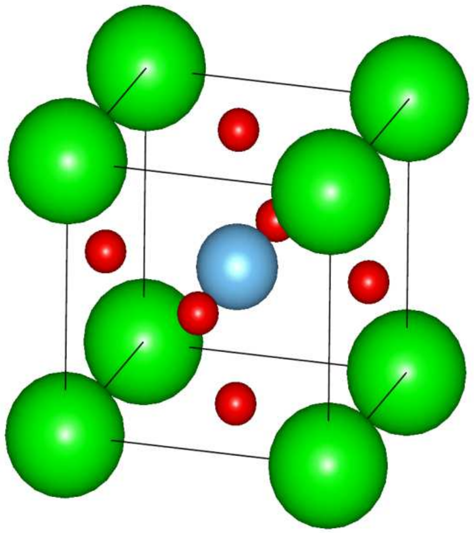


McQuarry M., J. Am. Ceram Soc. 38, 1955

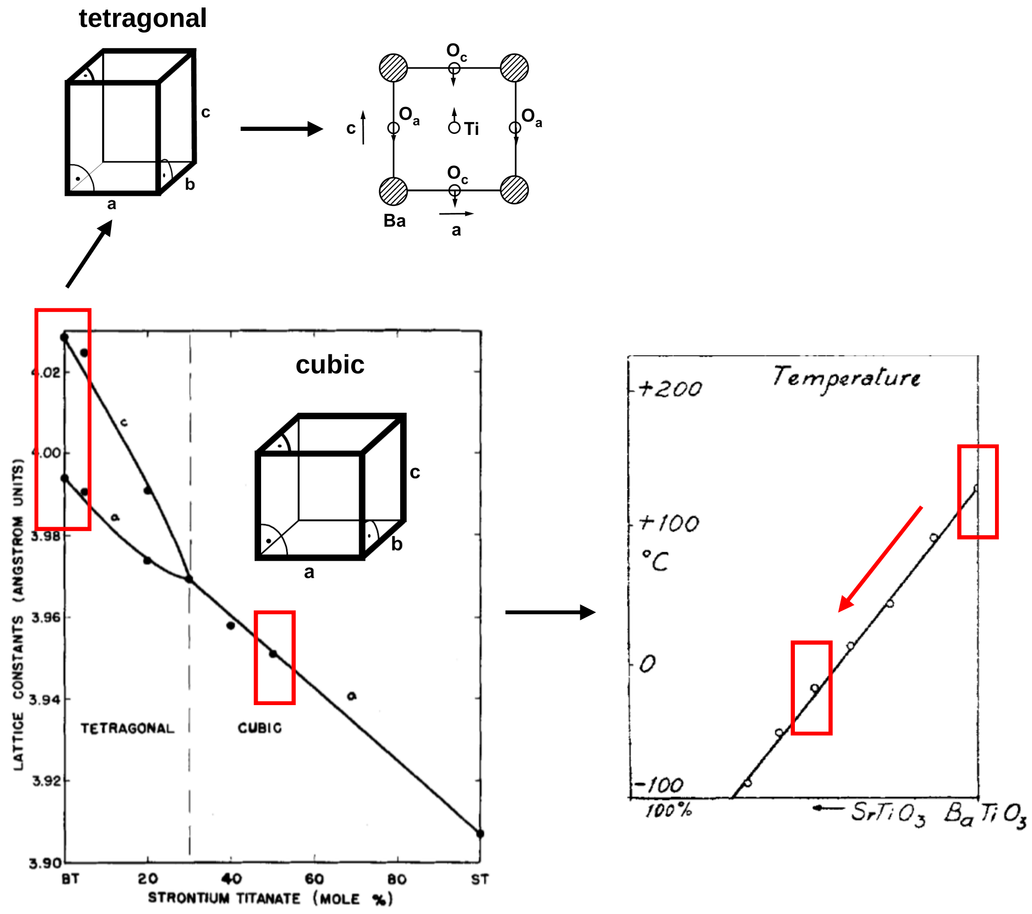


$$\tau_\varepsilon(E) = \frac{\varepsilon_r(E=0) - \varepsilon_r(E)}{\varepsilon_r(E=0)}$$

$Ba_{0,6}Sr_{0,4}Ti_{1-x}Fe_xO_{3-y}F_y$



ABO_3 Perovskite-Structure



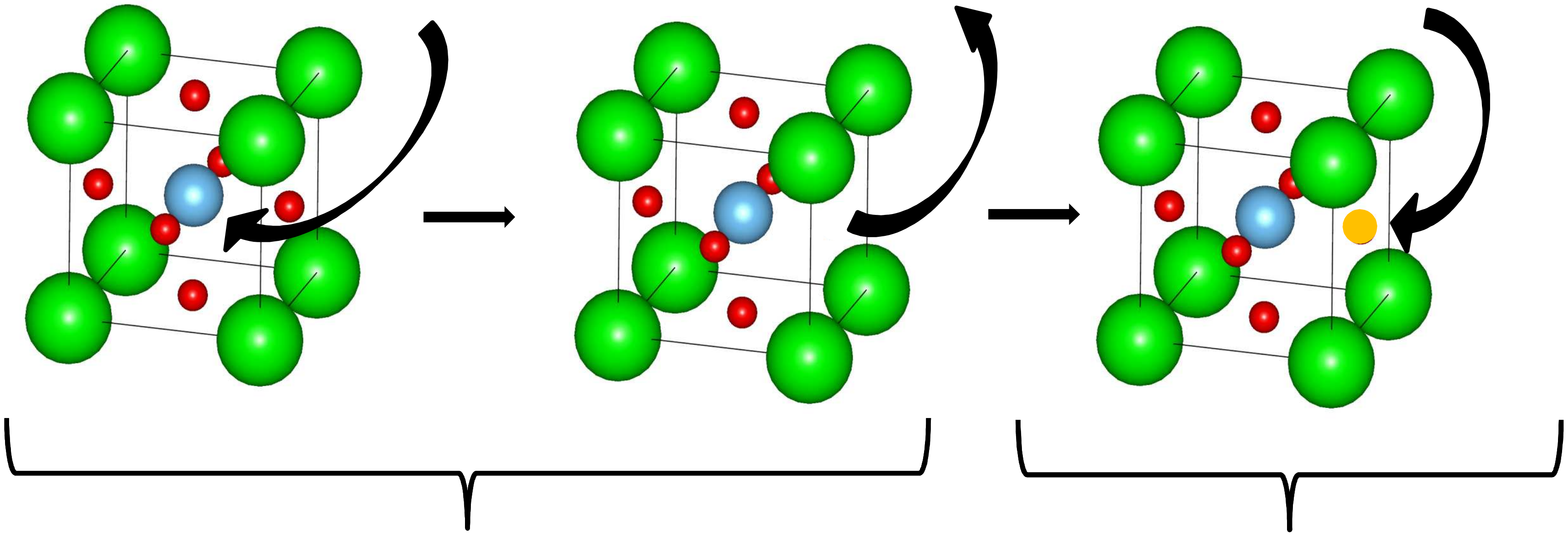
Jeon J.-H., J. Eur. Ceram. Soc. 24, 2004

🟩 Ba^{2+} Sr^{2+}

🔵 Ti^{4+} **$Fe^{2+/3+}$**

🔴 O^{2-} **F^-**

$Ba_{0,6}Sr_{0,4}Ti_{1-x}Fe_xO_{3-y}F_y$



Acceptor doping with

Formation of

Donator doping with

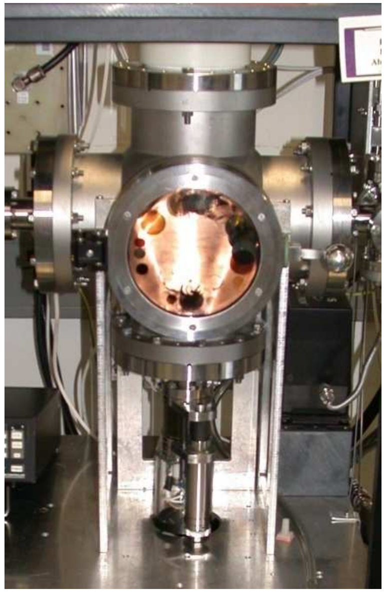
Formation of single charged defect complexes

Adjusting *tunability* by donor co-doping

<u>THEORY:</u> Defect complexes influencing the quality factor Q, the permittivity and tunability

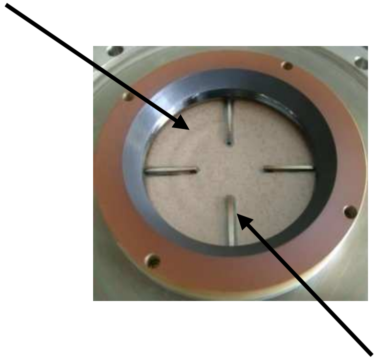
$Q = 1/\tan\delta$

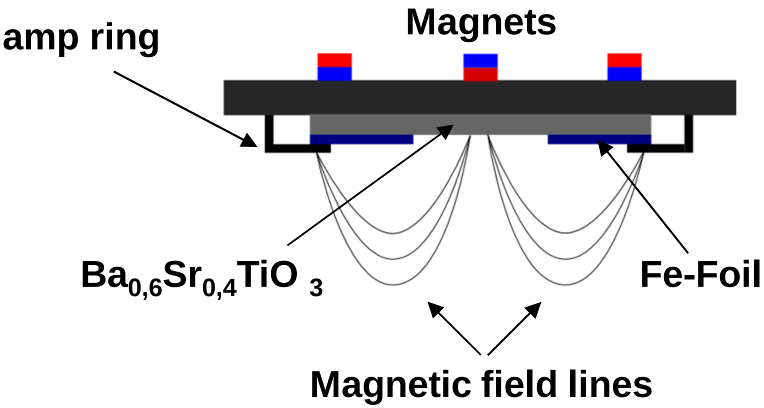
Thin Film Processing – *Iron Dopant*



RF Magnetron Co-Sputter Deposition

- RF sputtering power: 85W
- Sputtergas composition: 80 vol% Ar   20 vol% O_2
- Base pressure: < 10^{-6} mbar
- Operating pressure: 10^{-2} mbar
- Thin films crystallization in a subsequent annealing process

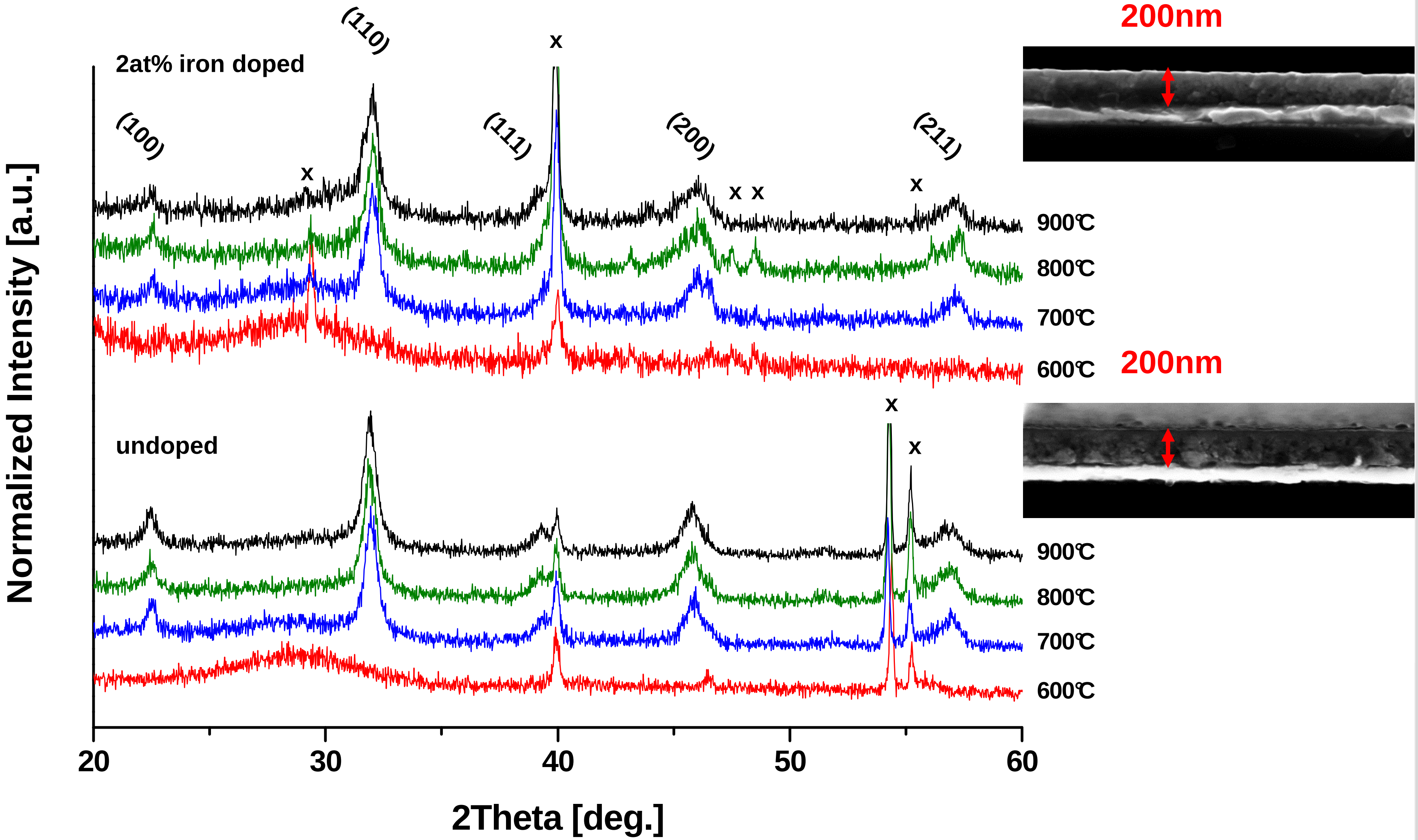




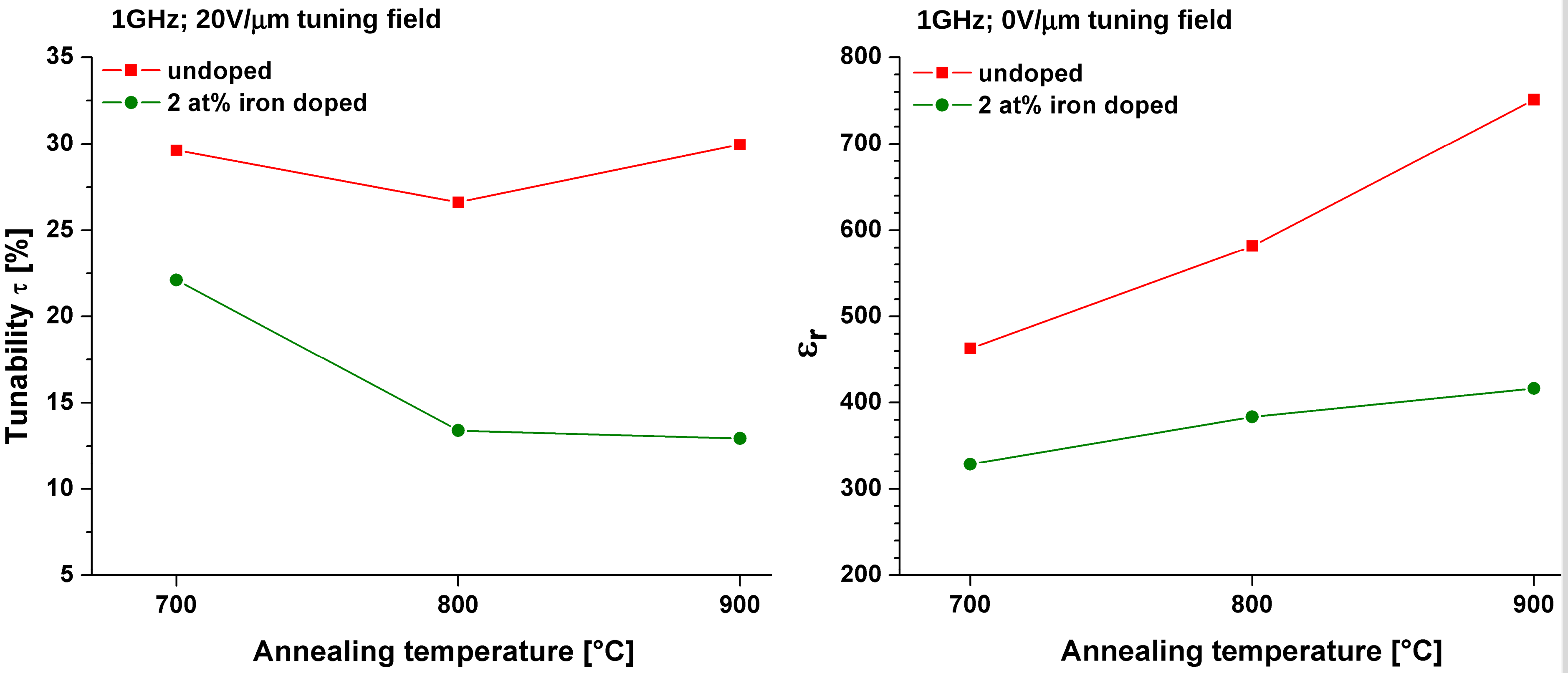
Target

- 3“ Co-Sputtertarget
- $Ba_{0,6}Sr_{0,4}TiO_3$; Kurt Lesker Ltd
- ***Ironfoil***; Goodfellow GmbH
- Multilayer substrate; Inostec Inc.

Thin Film Characterization – Crystal Structure



Thin Film Characterization – *Microwave Performance*



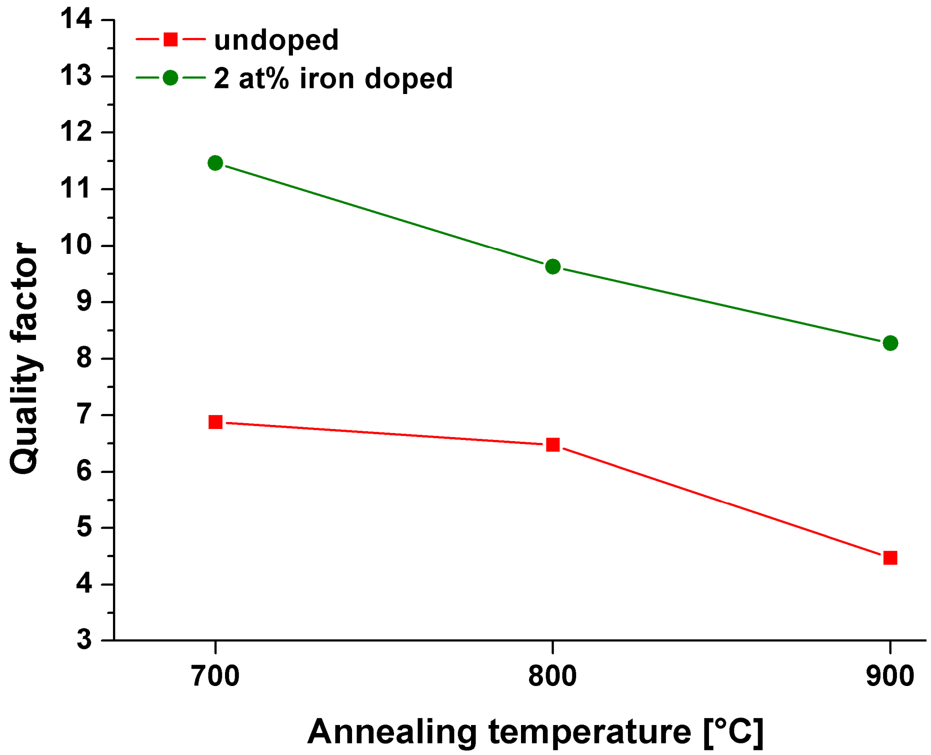
→ **Influence of acceptor dopant on tunability and permittivity**

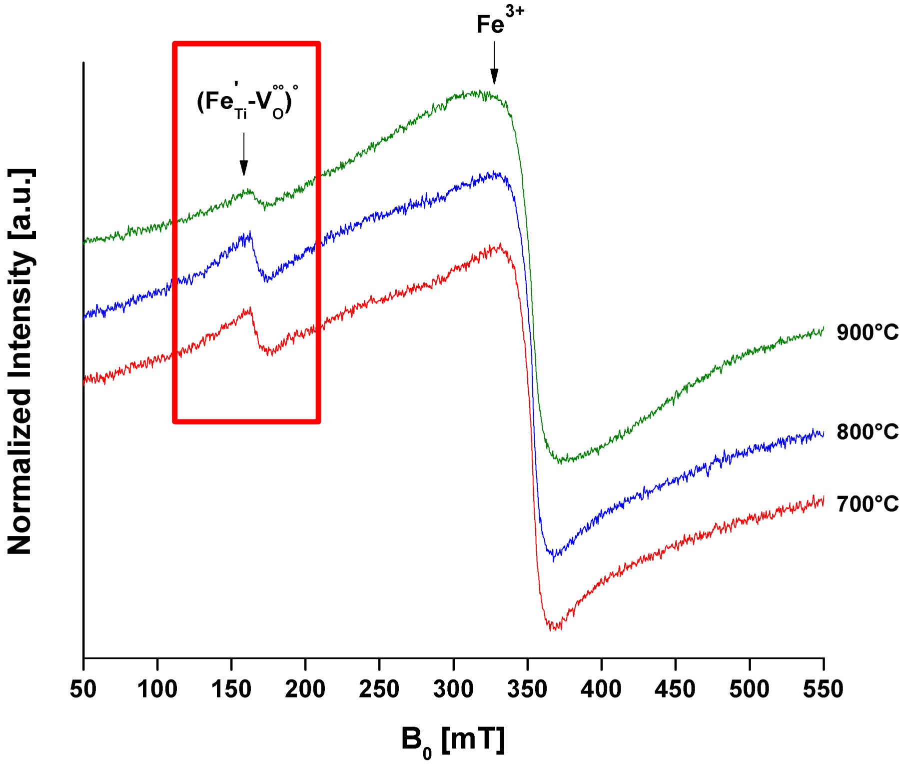
→ **Permittivity strongly influenced by subsequent thermal processing**

Thin Film Characterization – *Microwave Performance*

Electron Paramagnetic Resonance Spectroscopy (EPR)

1GHz; 0V/µm tuning field

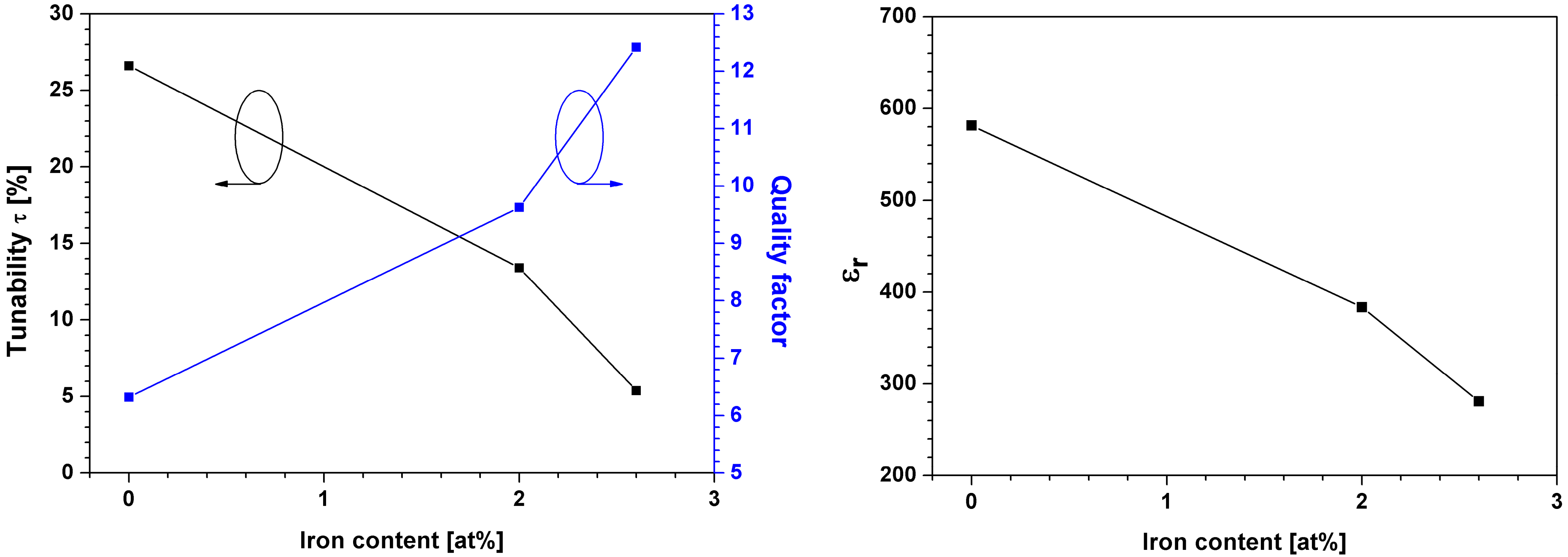




- → **Enhancement of the Q-factor due to acceptor doping**
- → **Verification of the defect dipol complex**

Thin Film Characterization – *Microwave Performance*

Iron doped BST thin films



Tunability @ 1GHz; 20V/µm tuning field
Q-factor @ 1GHz; 0V/µm tuning field

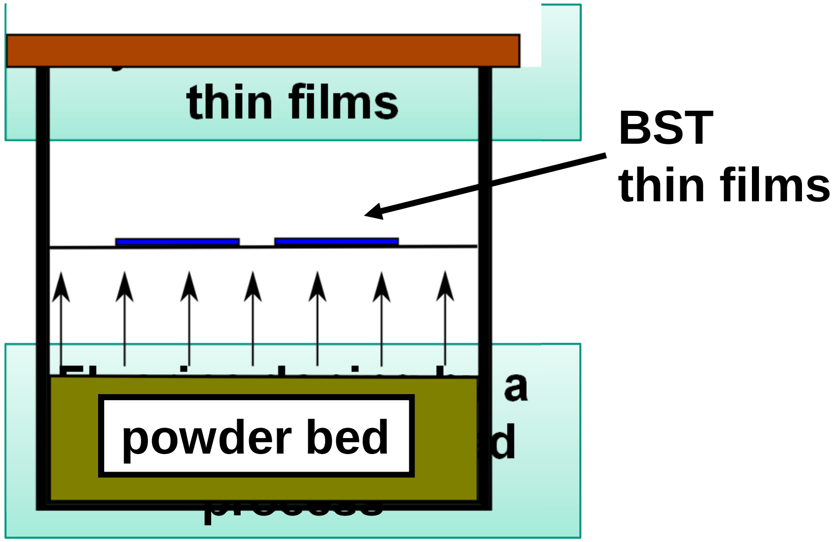
→ **Q-factor enhancement depends on the amount of iron acceptor dopant**

Thin Film Processing – Fluorine *Co-Dopant*

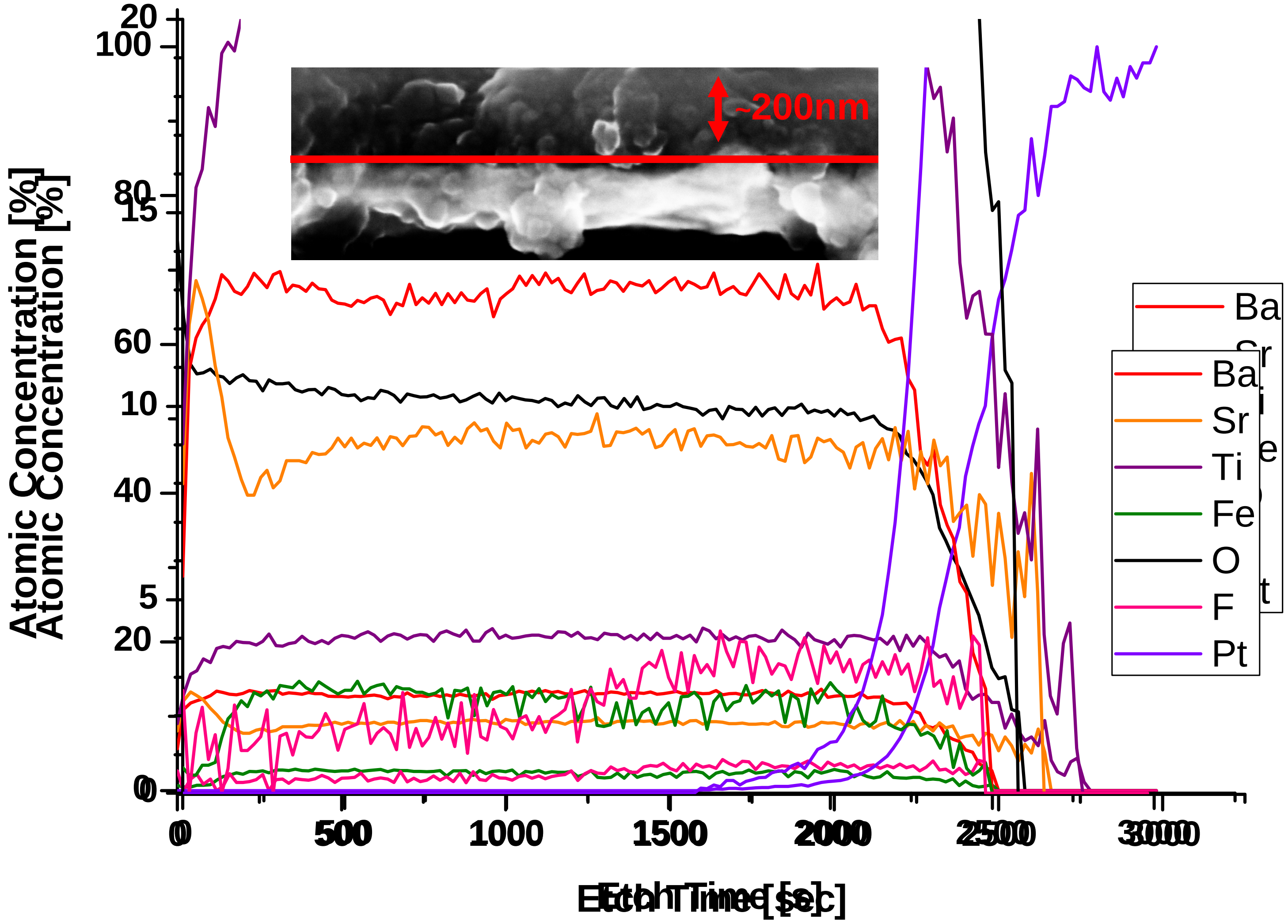
Deposition without internal heating
(RF Magnetron Co-sputter Process)

1. Annealing Process
(1h@800 C)

2. Annealing Process
(4h@700 C)

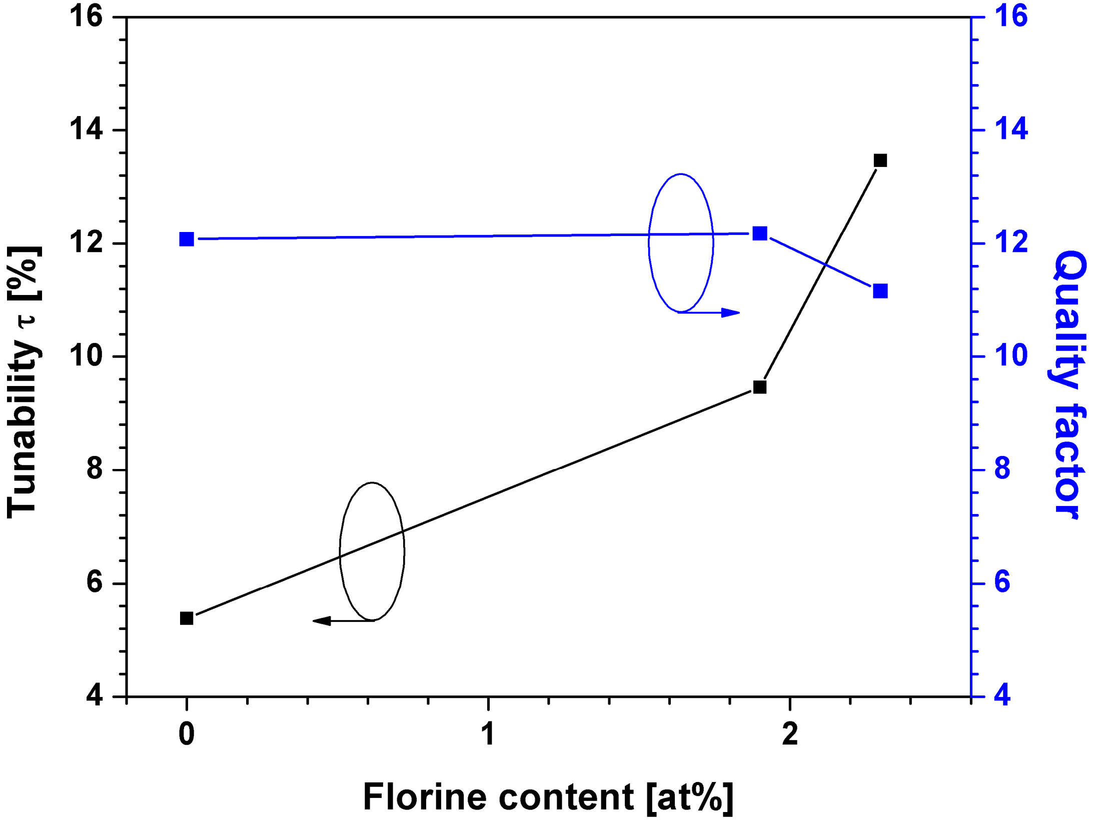


Thin Film Characterization – *XPS Sputter Depth Profiling*



Thin Film Characterization – *Microwave Performance*

Iron/Fluorine co-doped BST thin films



Tunability @ 1GHz; 20V/µm tuning field
Q-factor @ 1GHz; 0V/µm tuning field

- → **Nearly constant iron content in the BST films**
- → **Enhancement of tunability depends on the Fluorine donator dopant**

Summary

- **Achieved iron/fluorine co-doping by combined RF magnetron co-sputter deposition and subsequent annealing processes**
- **Enhanced quality factor Q due to iron acceptor dopant**
- **Proof of single charged defect complex**
- **Enhanced tunability due to fluorine co-doping**

Thanks to…

- ***Institute for Applied Materials –***
  Material Process Technology, KIT

  H. Geßwein, M. Schroeder, J. R. Binder, M. Bruns
- ***Institut für Physikalische Chemie I, Uni Freiburg***

  M. D. Drahus, R.-A. Eichel
- ***Microwave Engineering, TU Darmstadt***

  M. Sazegar