LABORATORY of ADVANCED MATERIALS and MICRODEVICES

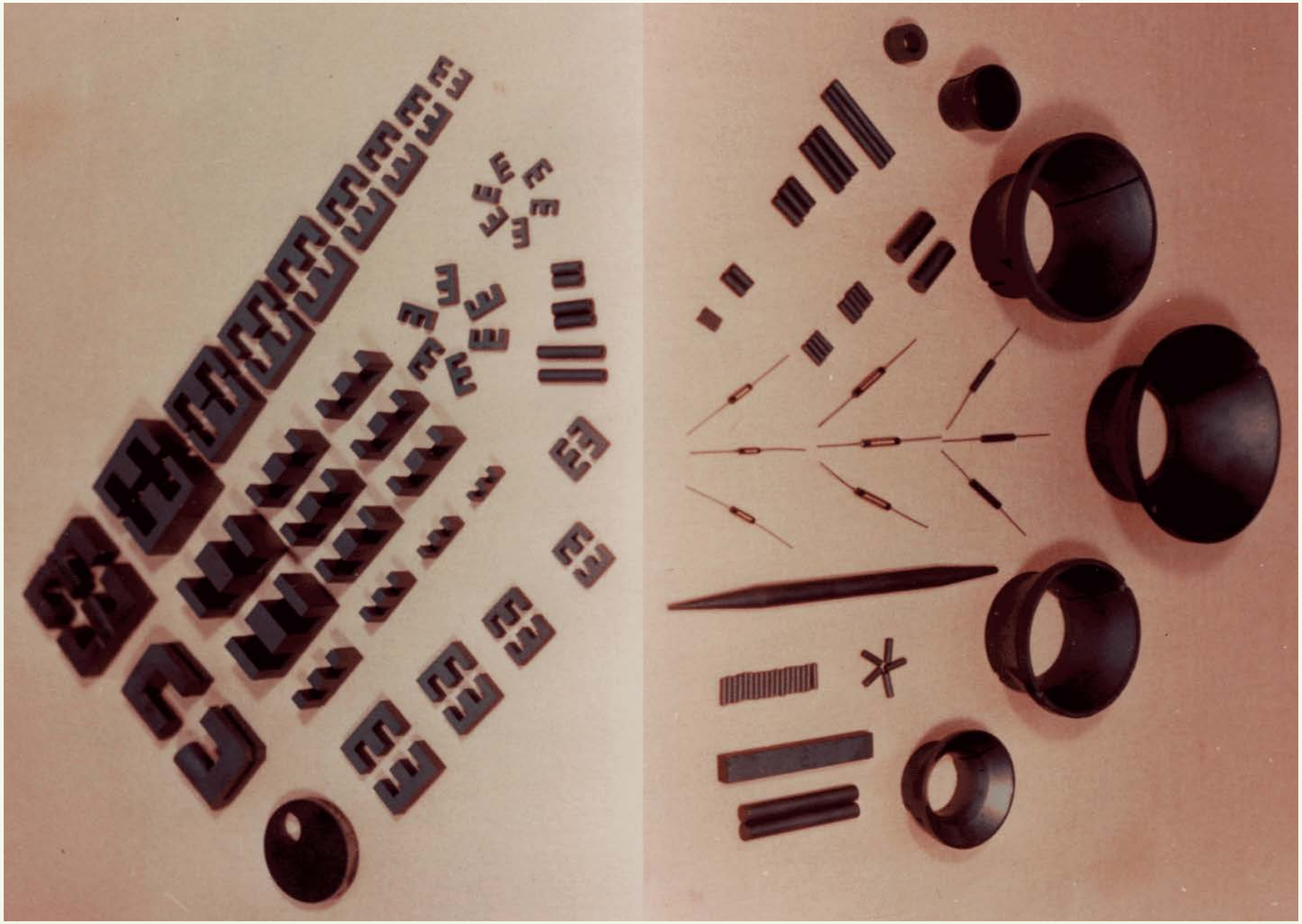
Prospects and Plans

N. Martirosyan

Topics

- Categorization of Advanced/Smart Materials
- High-Temperature Synthesis of Complex Materials
- Ceramic-Based Devices
- Preparing of Nanostructures and Nanodevices
- Design and Programing of Hardware

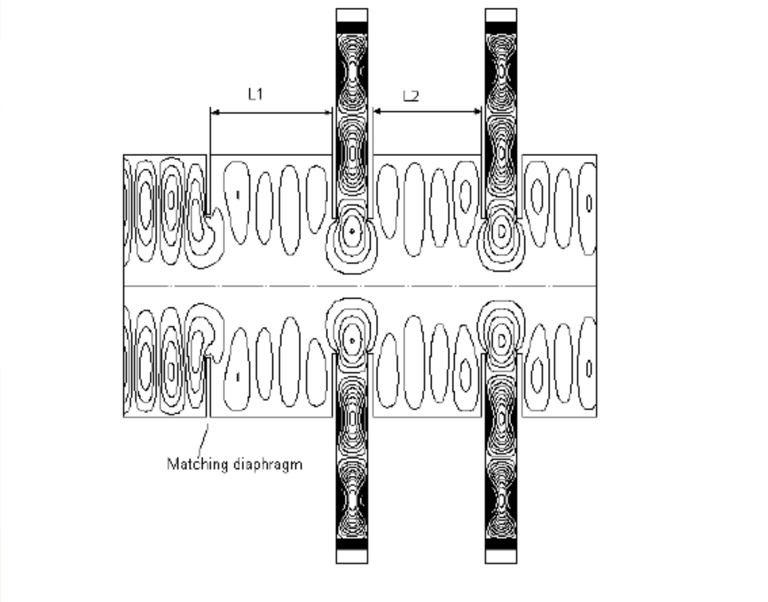
Magnetic Materials (Ferrites)



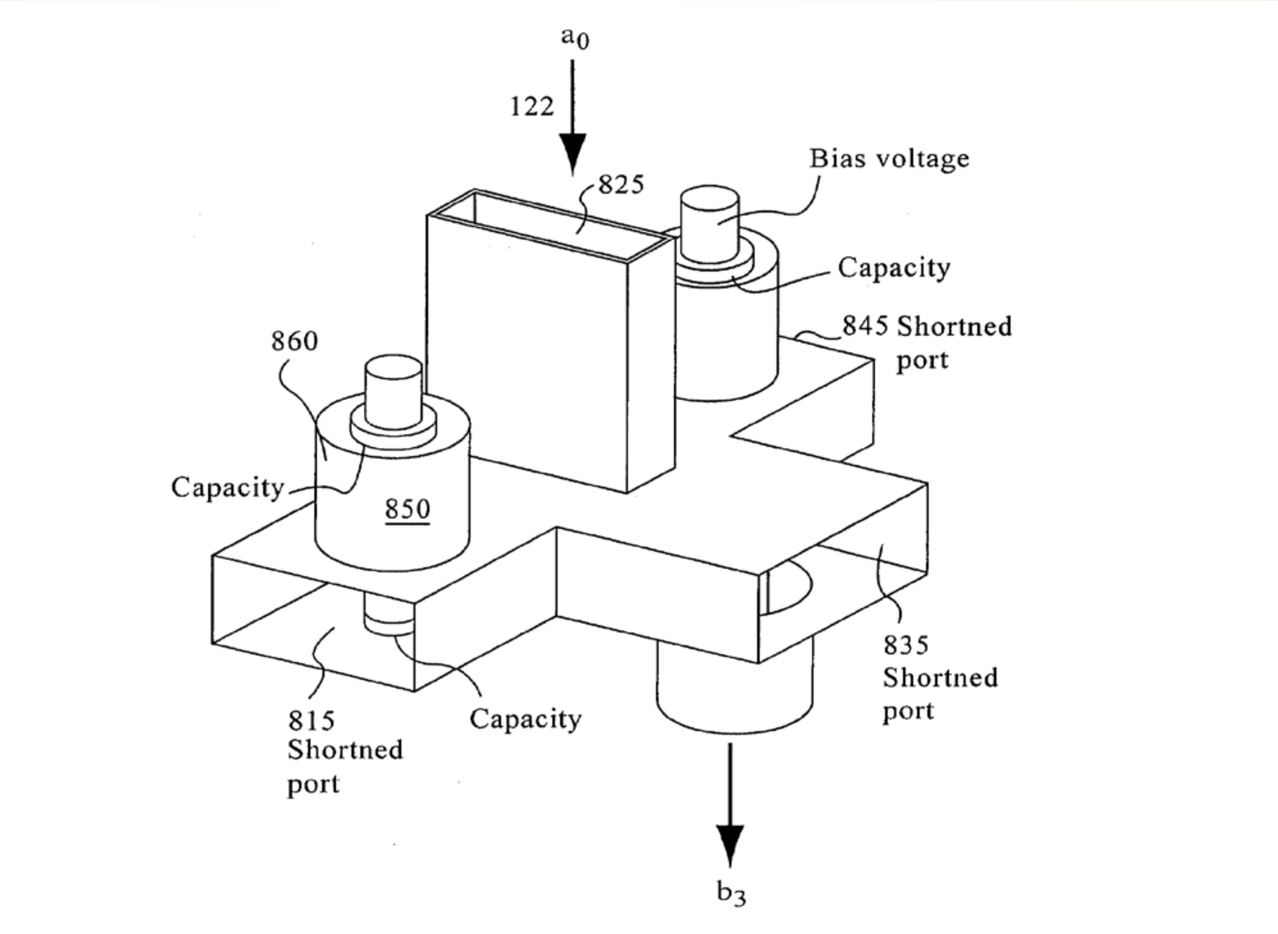
Materials for Applications in Electron Accelerators

- Ferroelectric materials based on BSTO compositions.
- Multi-Ferroic materials based on BFO-BSTO-MZFO compositions.
- Production of fast RF phase shifters and amplitude modulators from the above-mentioned materials.

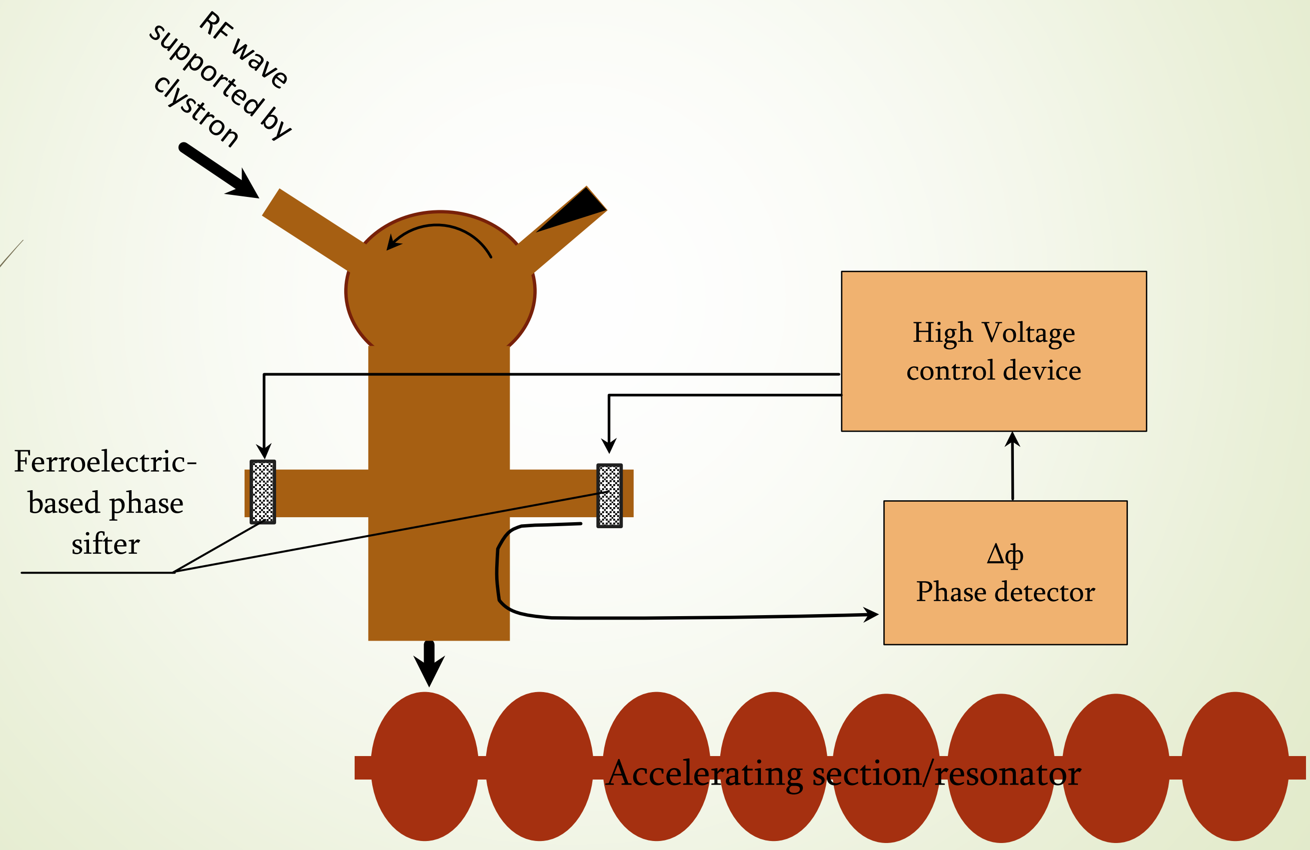
Prototype BST(M) ferroelectric ring sample



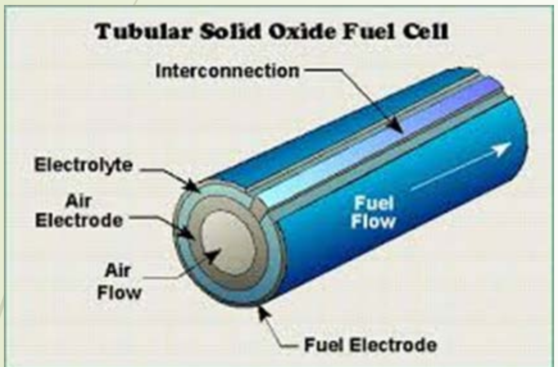
RF phase shifter

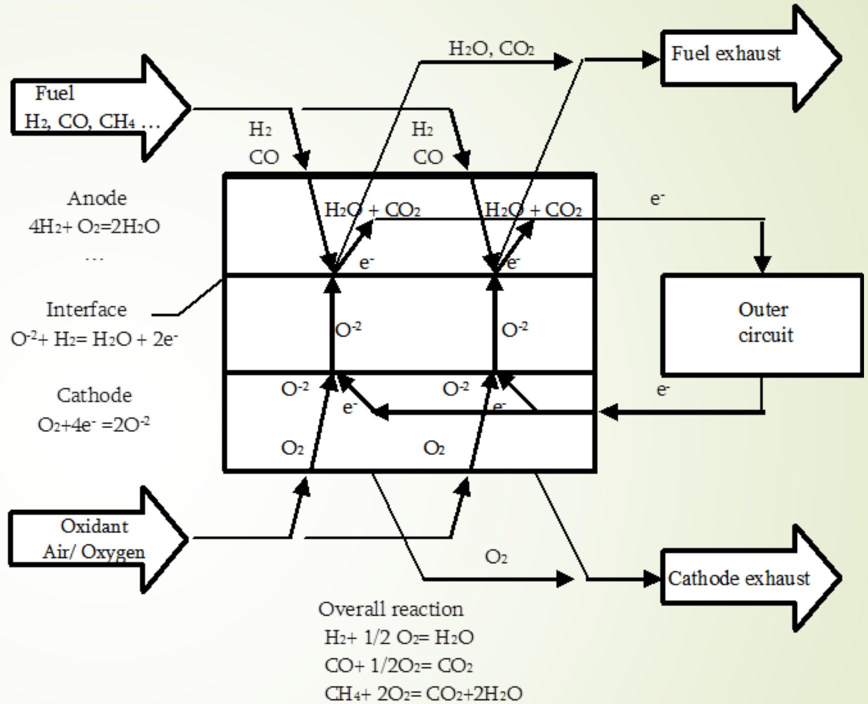


The Scheme of RF Wave Phase Shifter

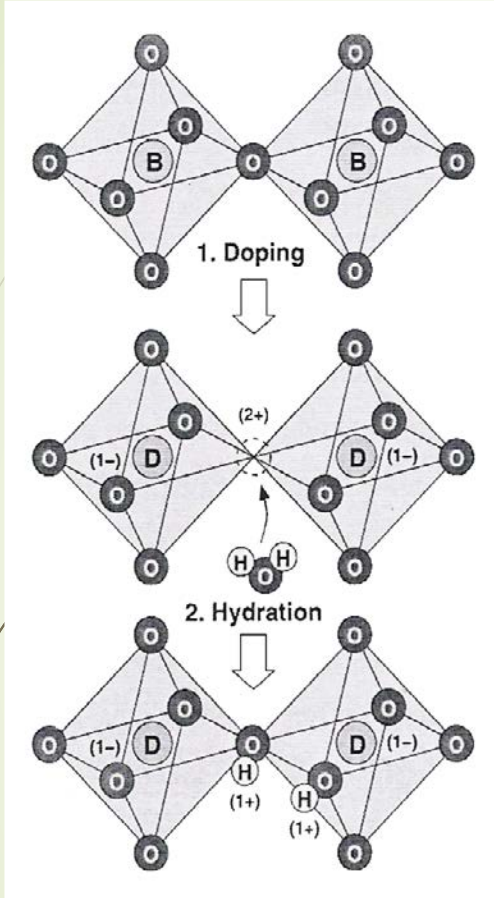


The Schematic Diagram of the Reaction in SOFC with Proton Conductivity

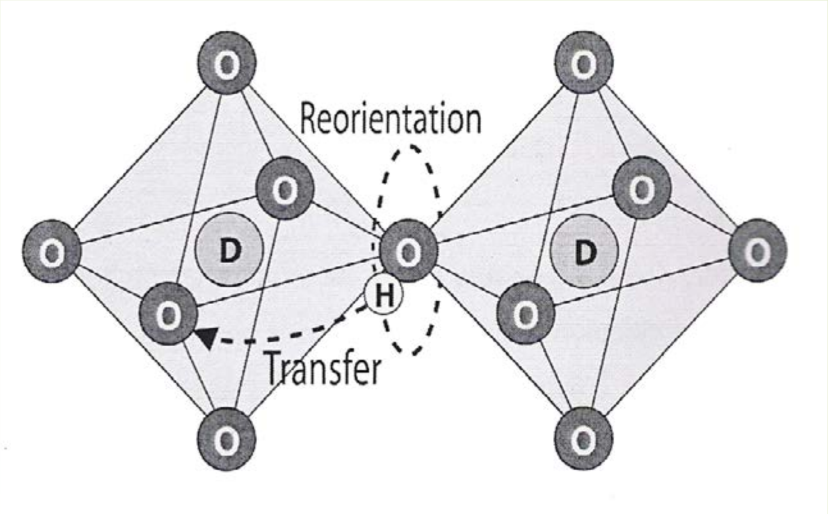




The Proton Conductivity Mechanism in Doped Structures



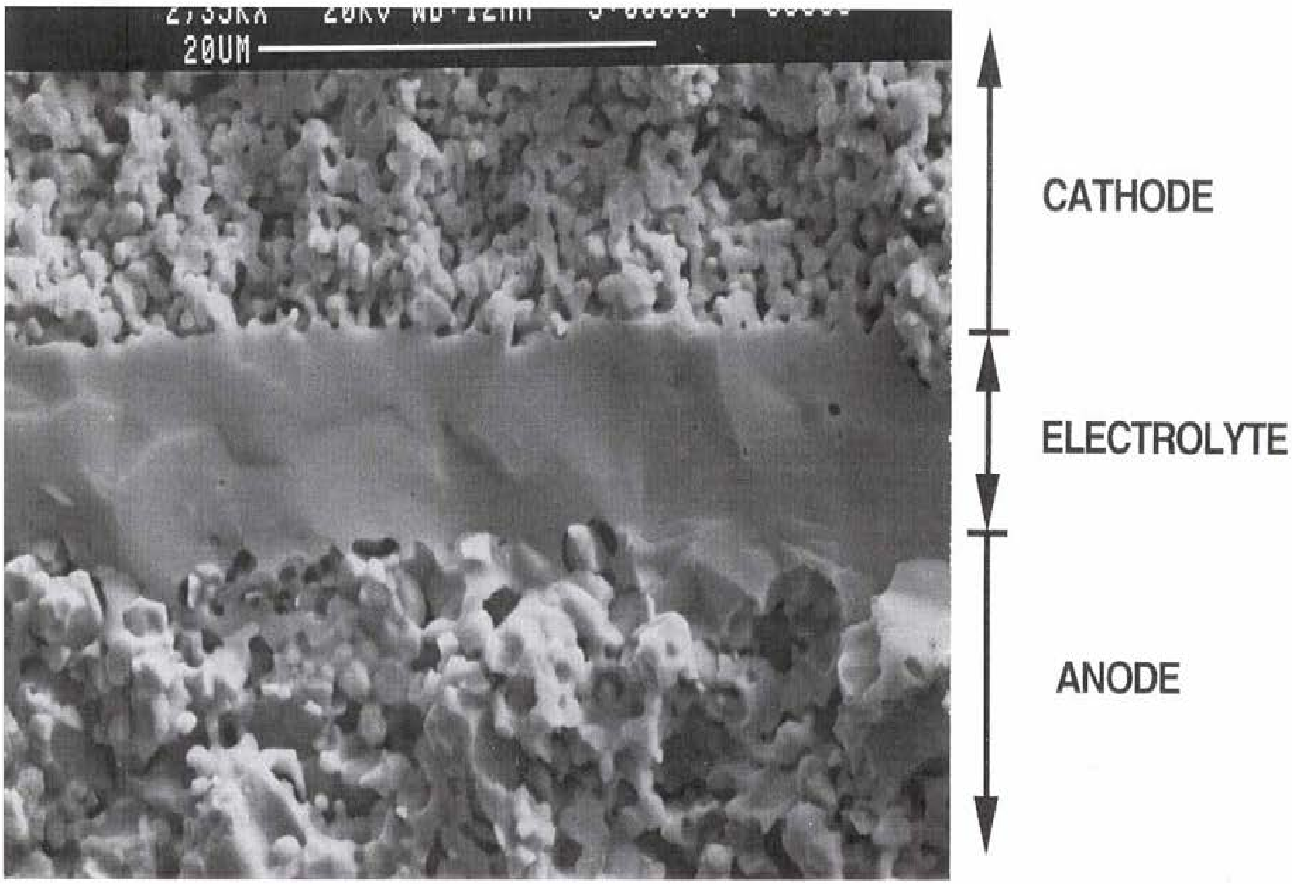
a)



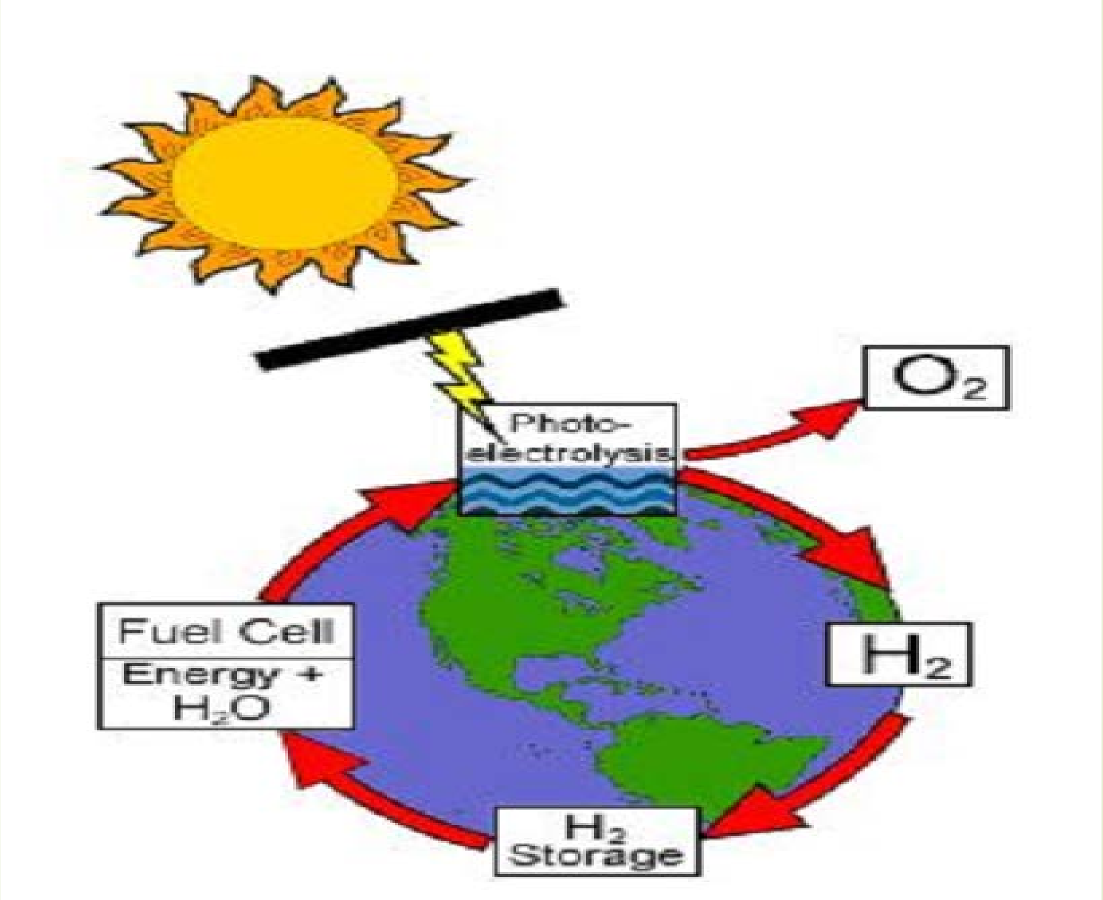
b)

a) A schematic picture of the formation and filling of an oxygen vacancy by doping with lower-valence ions (D) at the B-site and subsequent hydration in water vapour,
b) The Grotthuss mechanism involves a reorientation step and a proton transfer step, which is schematically illustrated for a hydrated perovskite.

Typical Cell Microstructure



Renewable Energy: Production of Hydrogen from Solar Energy

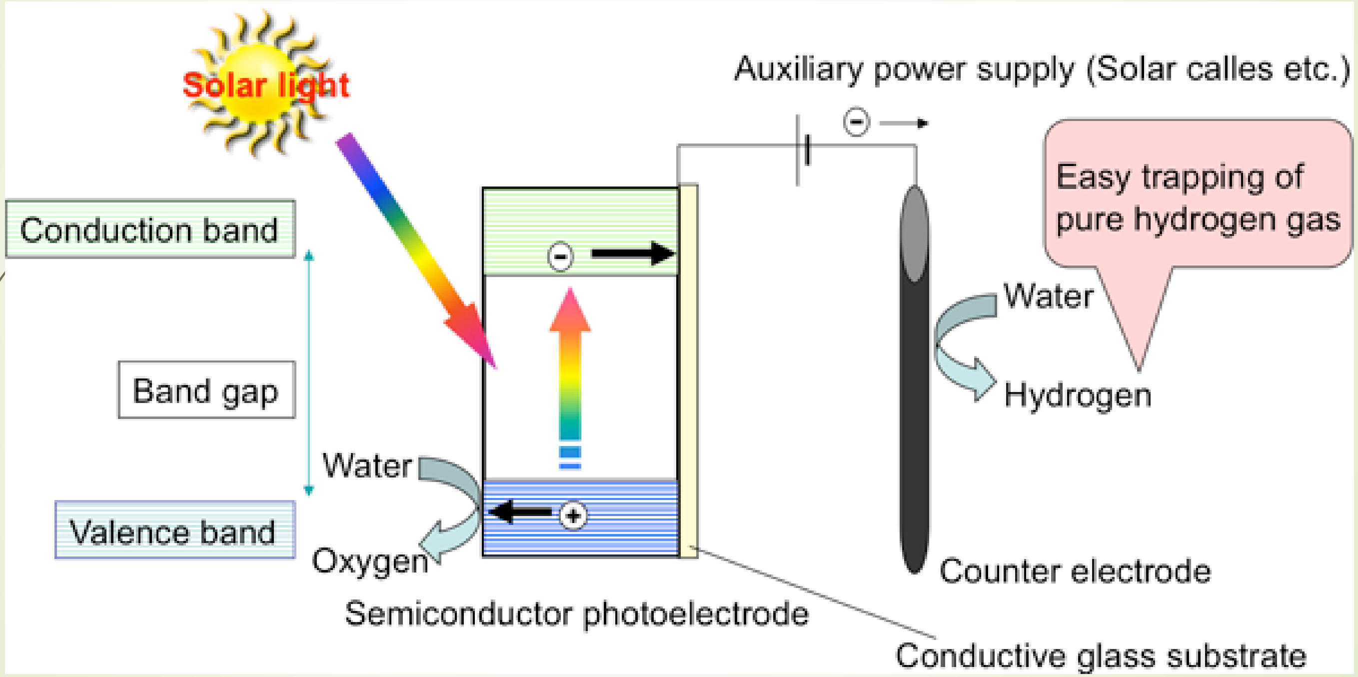


The Scheme of Hydrogen Production from Sunlight

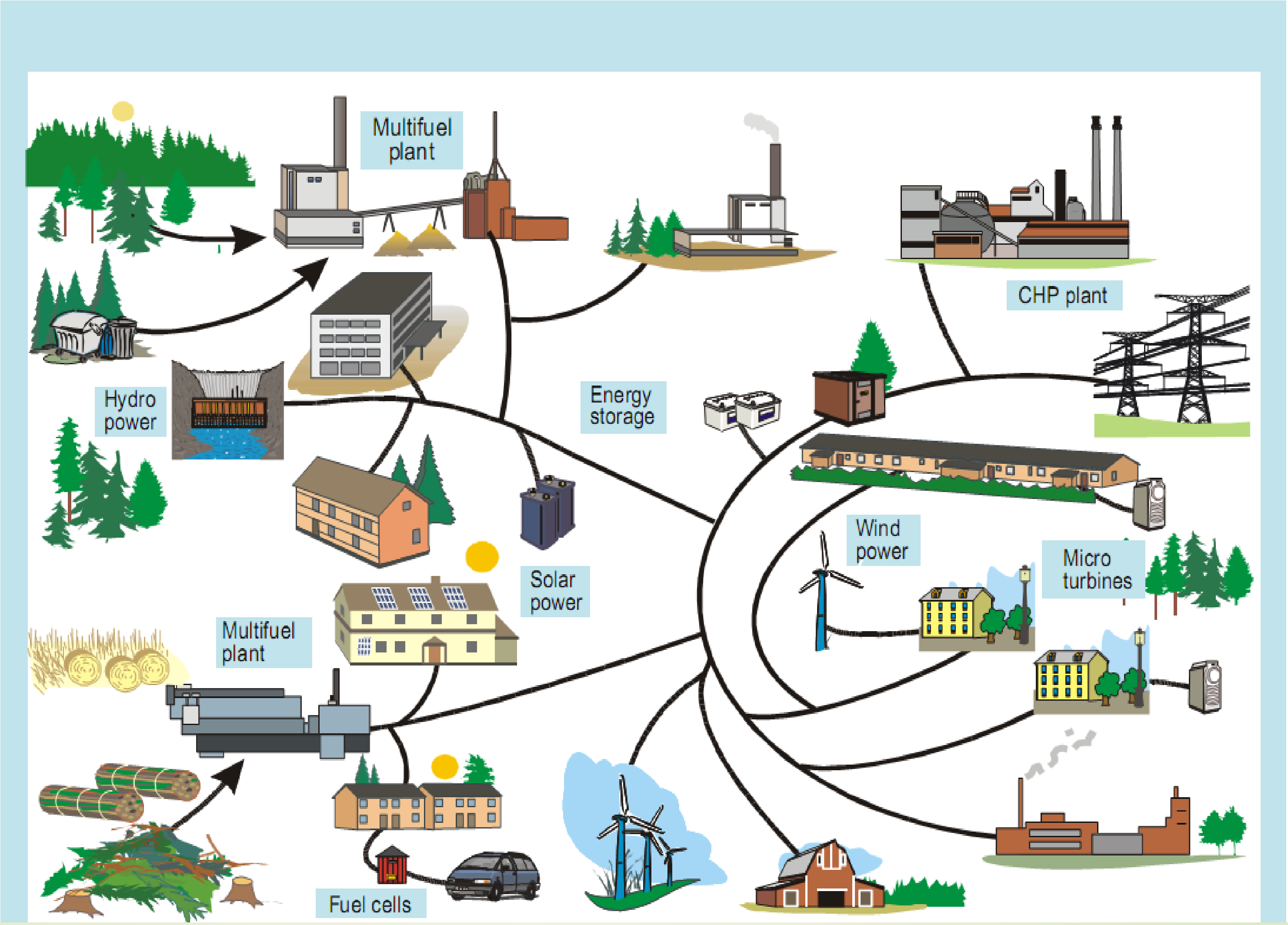
Sun Light $+ M_xFe_{3-x}O_4 \rightarrow Me_xFe_{3-x}O_{4-\xi} + \xi/2 O_2\uparrow$,

$Me_xFe_{3-x}O_{4-\xi} + H_2O \rightarrow M_xFe_{3-x}O_4 + \xi H_2\uparrow$:

Photoelectrolysis of Water

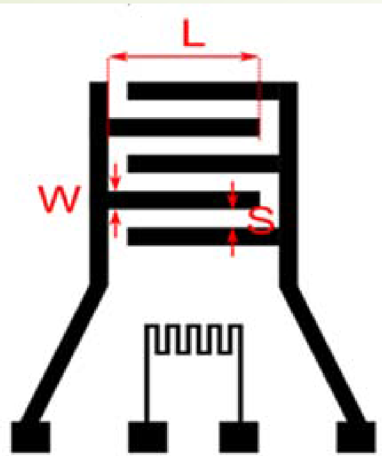


Implementation of Distributed Resources



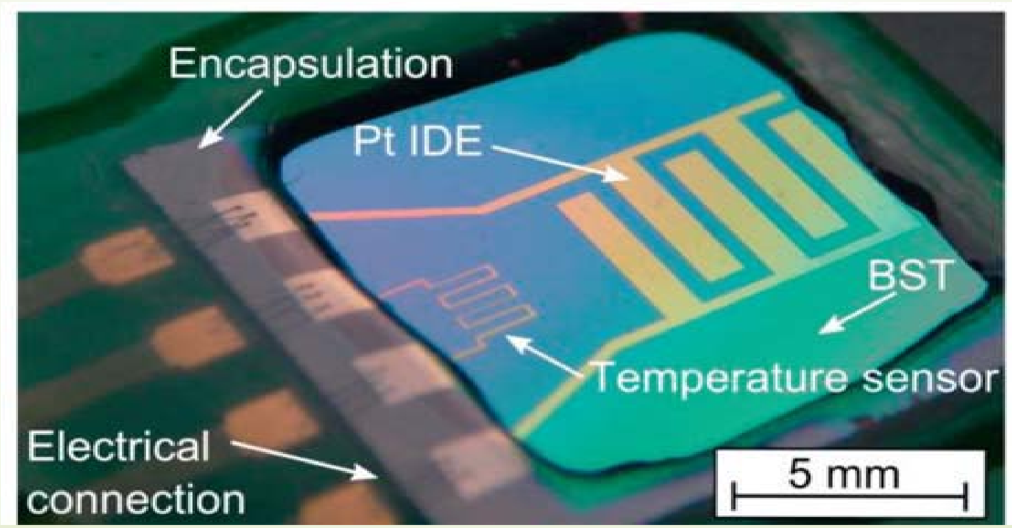
A Fabricated Nano-layer Structure Chip - (B) and Sizes of IDE Geometry - (A)

a)

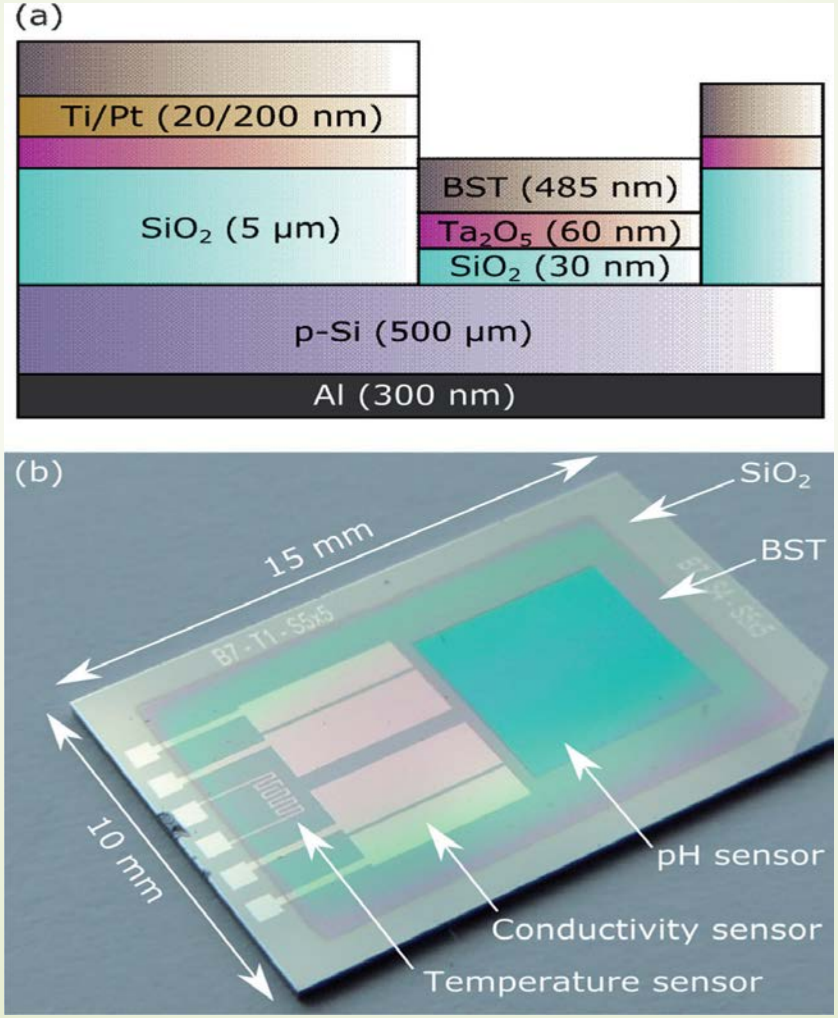


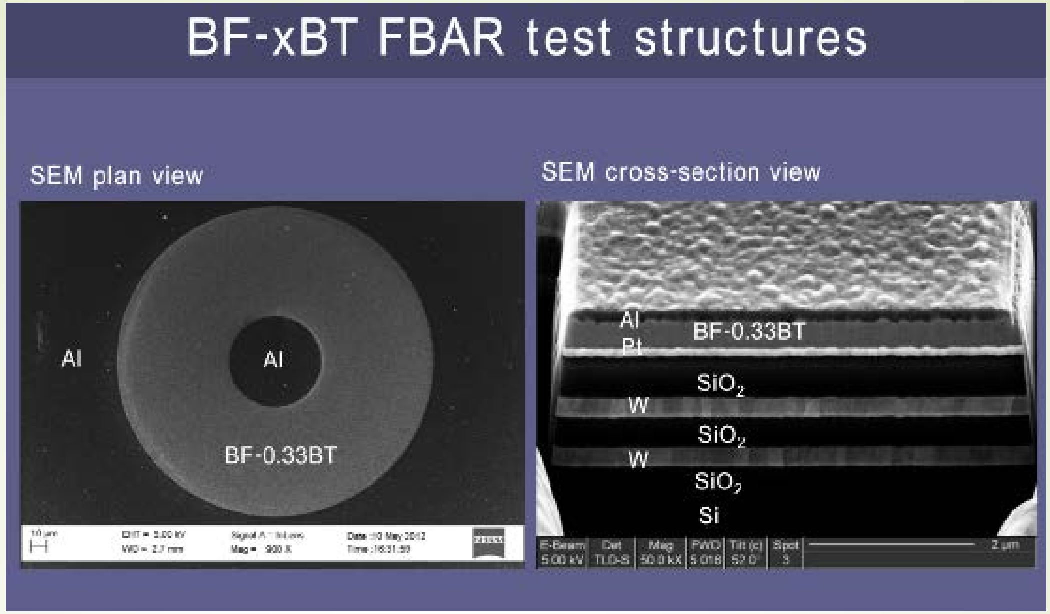
Finger number	50
Finger width W	600 µm
Finger spacing S	324 µm
Finger length L	2900 µm
Surface area A	0.087 µm
Substrate, SiO_2	500 µm
Ti / Pt	(20 / 200) nm
BST	485 nm

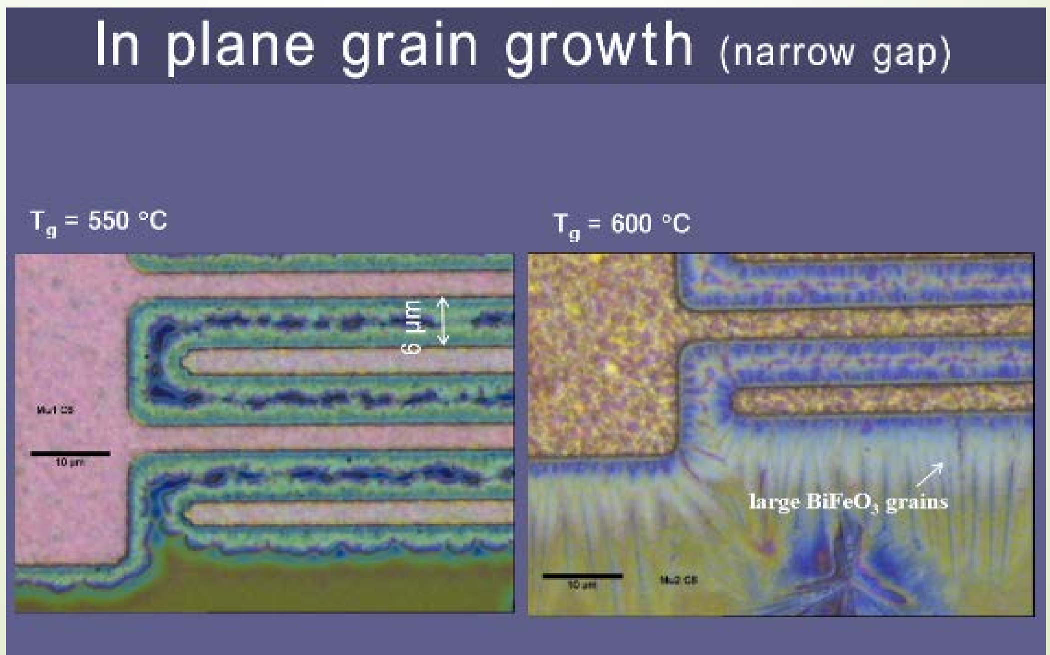
b)



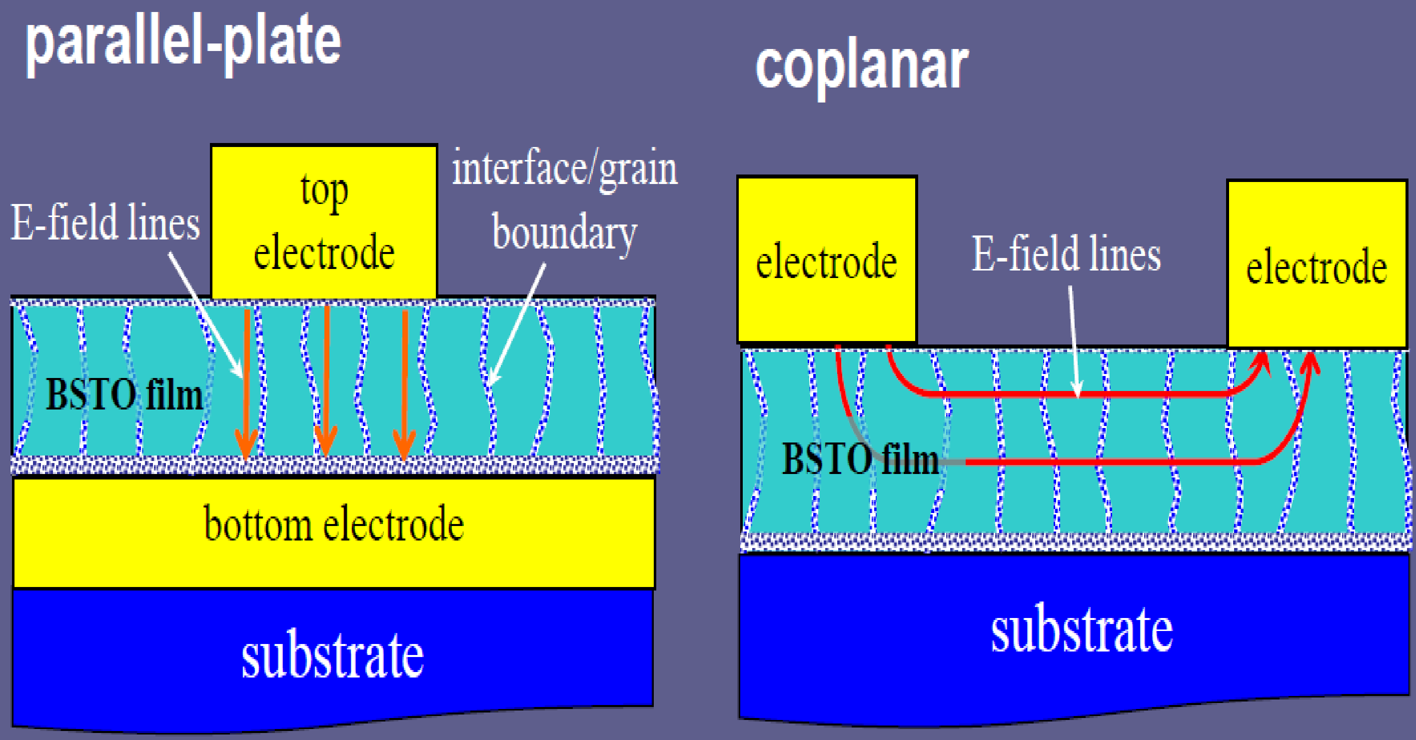
Schematic Cross Section (A) and Top View (B) of the Multiparameter Sensor Chip Coated with BST Layer as Multipurpose Material.




BF-xBT FBAR test structures
SEM plan view
Al
Al
BF-0.33BT
SEM cross-section view
Al
Pt
BF-0.33BT
SiO2
W
SiO2
W
SiO2
Si
2 µm


In plane grain growth (narrow gap)
Tg = 550 °C
6 µm
10 µm
Tg = 600 °C
large BiFeO3 grains
10 µm

Parallel-plate and coplanar designs



The Obtainment of Ceramic Samples

- Targets
  - Nano layer obtainment by PLD technology
  - Thin-layer obtainment by magnetron powder technology
- Capacitors
- Sensors
- Magnetic soft materials
- Magnetic strong materials
- Membranes/electrodes
  - For applications in hydrogen producing devices and solid oxide fuel cells

The Technology of Ferroelectric Nanostructure Production

Self Propagating High-temperature Syntheses (SHS)

The SHS method was developed on the basis of a scientific invention. In 1967 at the Branch of the Institute of Structural Macrokinetics and Material Science (ISMAN) of the USSR Academy of Sciences in Chernogolovka (a small town not far from Moscow), a new type of reaction between solid reagents in the mode of combustion yielding solid products was discovered in a search for new models of combustion in condensed media.

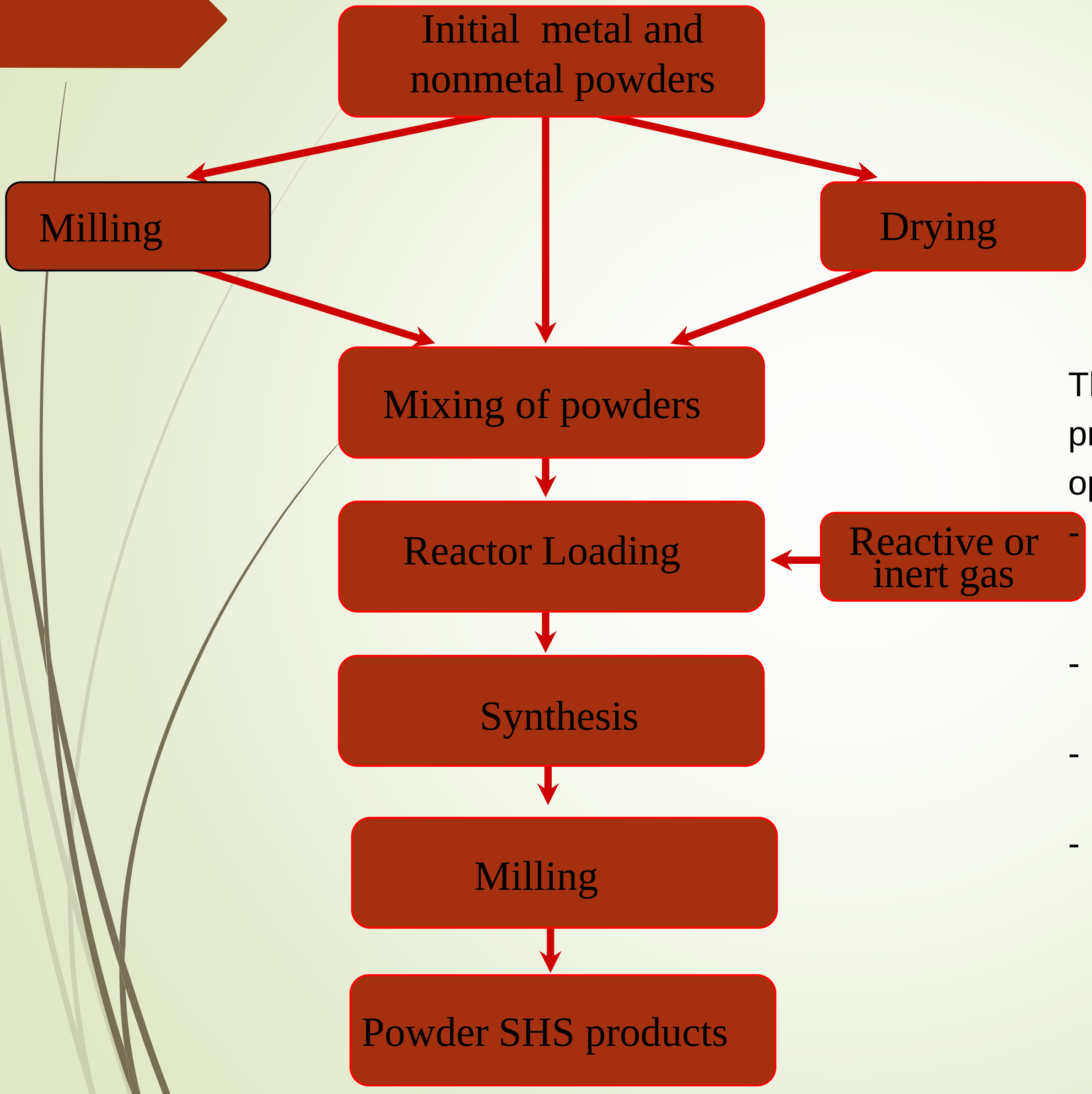
ISMAN

A.G. Merzhanov

Self-propagating high-temperature synthesis (SHS) means the synthesis of compounds (or materials) in a wave of chemical reaction (combustion) that propagates over starting reactive mixture owing to layer-by-layer heat transfer.

SHS naturally flew out of the discovery of the solid flame phenomenon. This discovery (officially named as "The Phenomenon of the Wave Localization of Solid-State Autoretarding Reactions") was made by A.G. Merzhanov, I.P. Borovinskaya, and V.M. Shkiro.

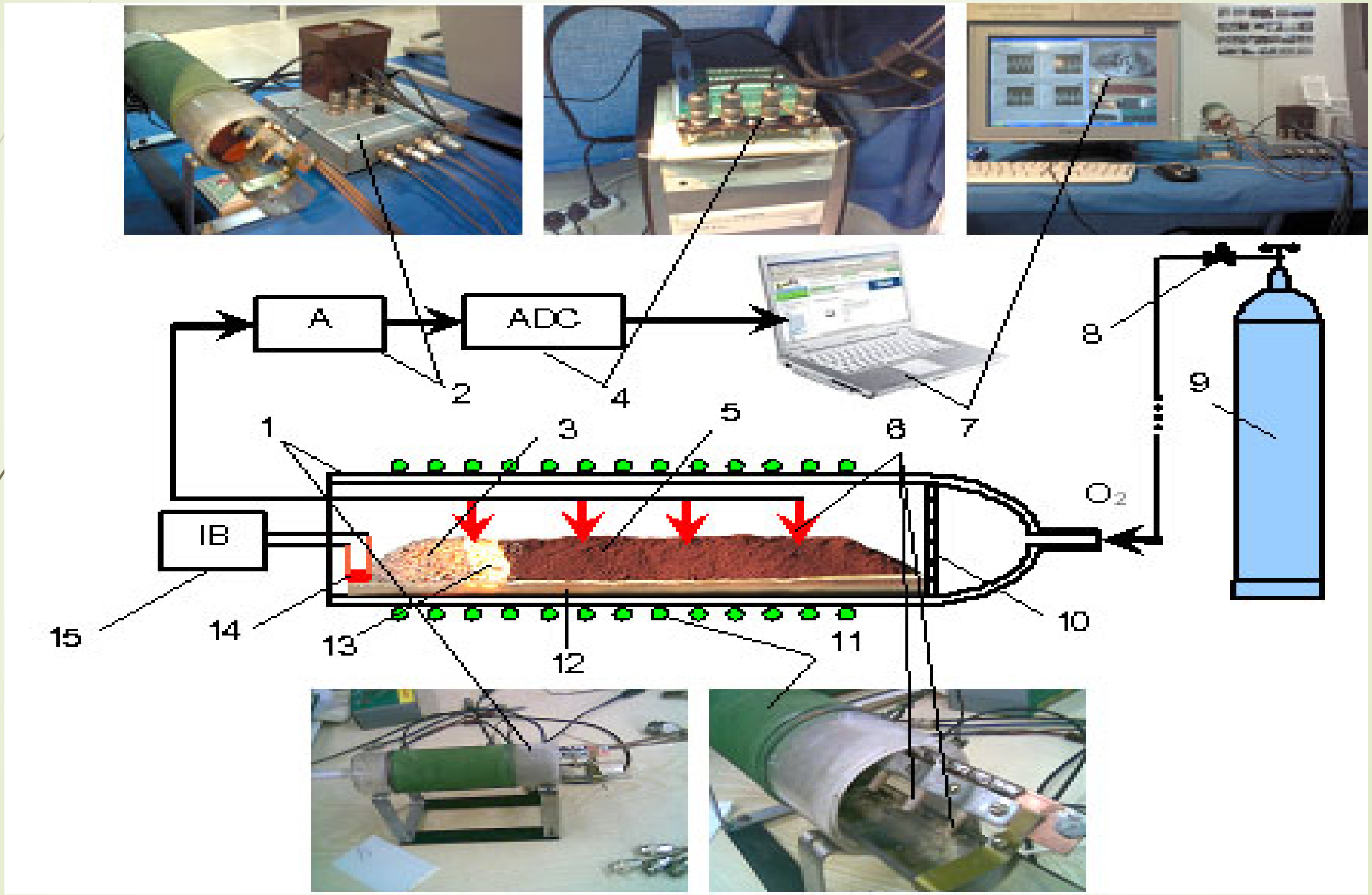
SHS Powder Production Technology



The technological scheme of powder production includes the following operations:

- preparation of a green mixture - milling, drying of components, mixing;
- filling of a reactor with a green mixture and gases;
- synthesis after a short–time thermal initiation;
- subsequent processing of synthesized products –milling, drying.

Experimental SHS Reactor

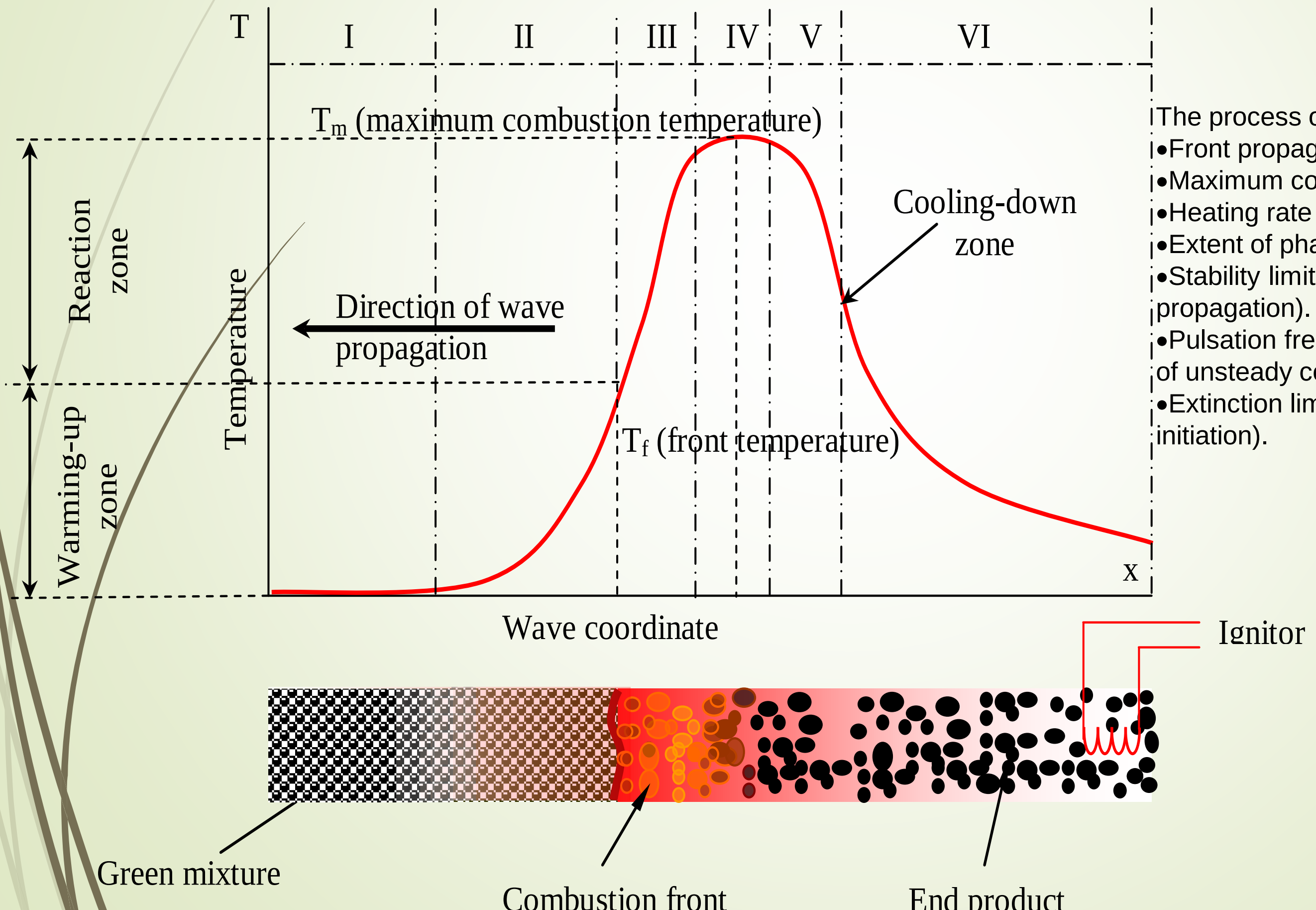


SHS Technological Types are Characterized by the Following Features

- low energy consumption (in most cases it is only necessary for initiating an SHS process);
- simple technological equipment, its high productive capacity and ecological;
- decreased number of technological stages in comparison with conventional technologies;
- feasibility of production lines adaptable to the production of different materials and items and amenable to mechanization and automation;

Temperature Distribution along Combustion Front Propagation

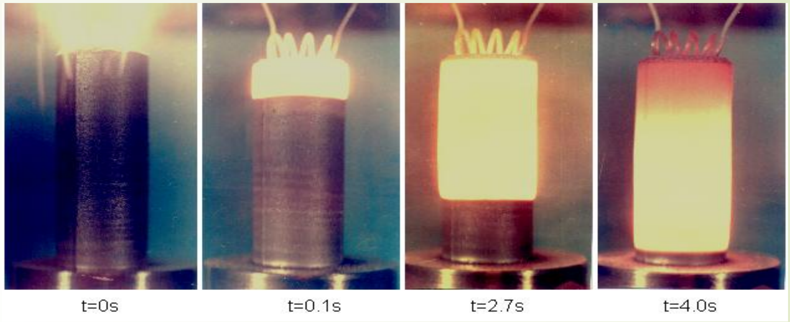
I-green mixture; II-warming-up zone; III-metal oxidation zone; IV-active oxidation of metal and formation of the intermediated; V-zone of secondary chemical interactions between intermediates and formation of final product; VI-cooling-down zone.

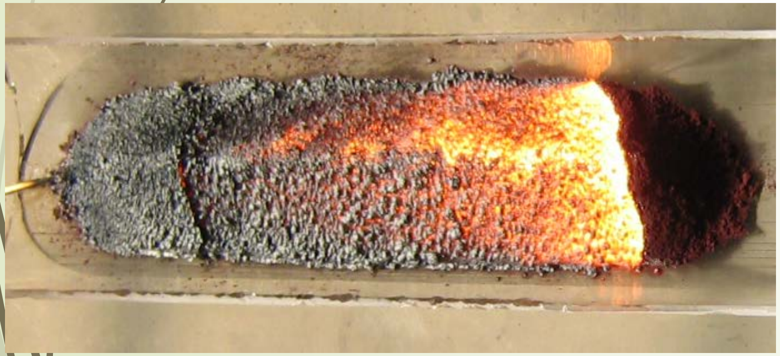


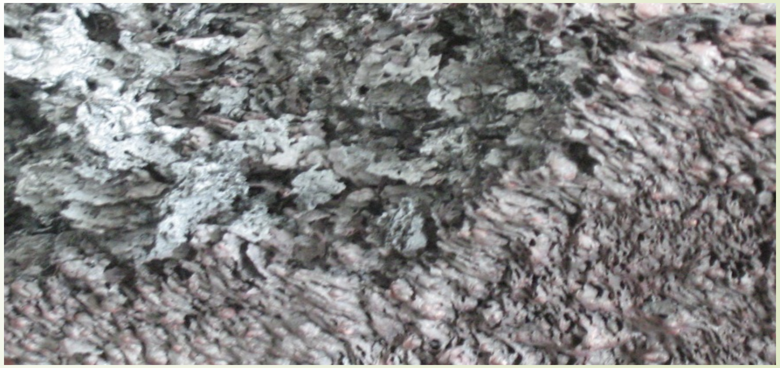
The process of wave propagation is characterized by:

- Front propagation (burning) velocity (0.1–0,4 cm/s).
- Maximum combustion temperature (1300–2000 K).
- Heating rate in the combustion front (10^3–10^6 K/s).
- Extent of phase/structure transformation.
- Stability limit (steady or unsteady wave propagation).
- Pulsation frequency, hot spot velocity, etc. (in case of unsteady combustion).
- Extinction limit (no combustion even upon intense initiation).

Photos of SHS Process







Chemical Classes of Reactions

Synthesis from the elements

$Ti + C = TiC$

$Ni + Al = NiAl$

$3Si + 2N_2 = Si_3N_4$

Redox reactions

$B_2O_3 + TiO_2 + 5Mg = TiB_2 + 5MgO$

$MoO_3 + B_2O_3 + 4Al = MoB_2 + 2Al_2O_3$

$3TiO_2 + C + 4Al = TiC + 2Al_2O_3$

Synthesis from compounds

$PbO + WO_3 = PbWO_4$

Oxidation of metals with complex oxides

$3Cu + 2BaO_2 + 1/2Y_2O_3 + 0.5(1.5 - x)O_2 = YBa_2Cu_3O_{7-x}$

$Nb + Li_2O_2 + 1/2Ni_2O_5 = 2LiNbO_3$

$8Fe + SrO + 2Fe_2O_3 + 6O_2 = SrFe_{12}O_{19}$

Reaction of the elements with decomposition products

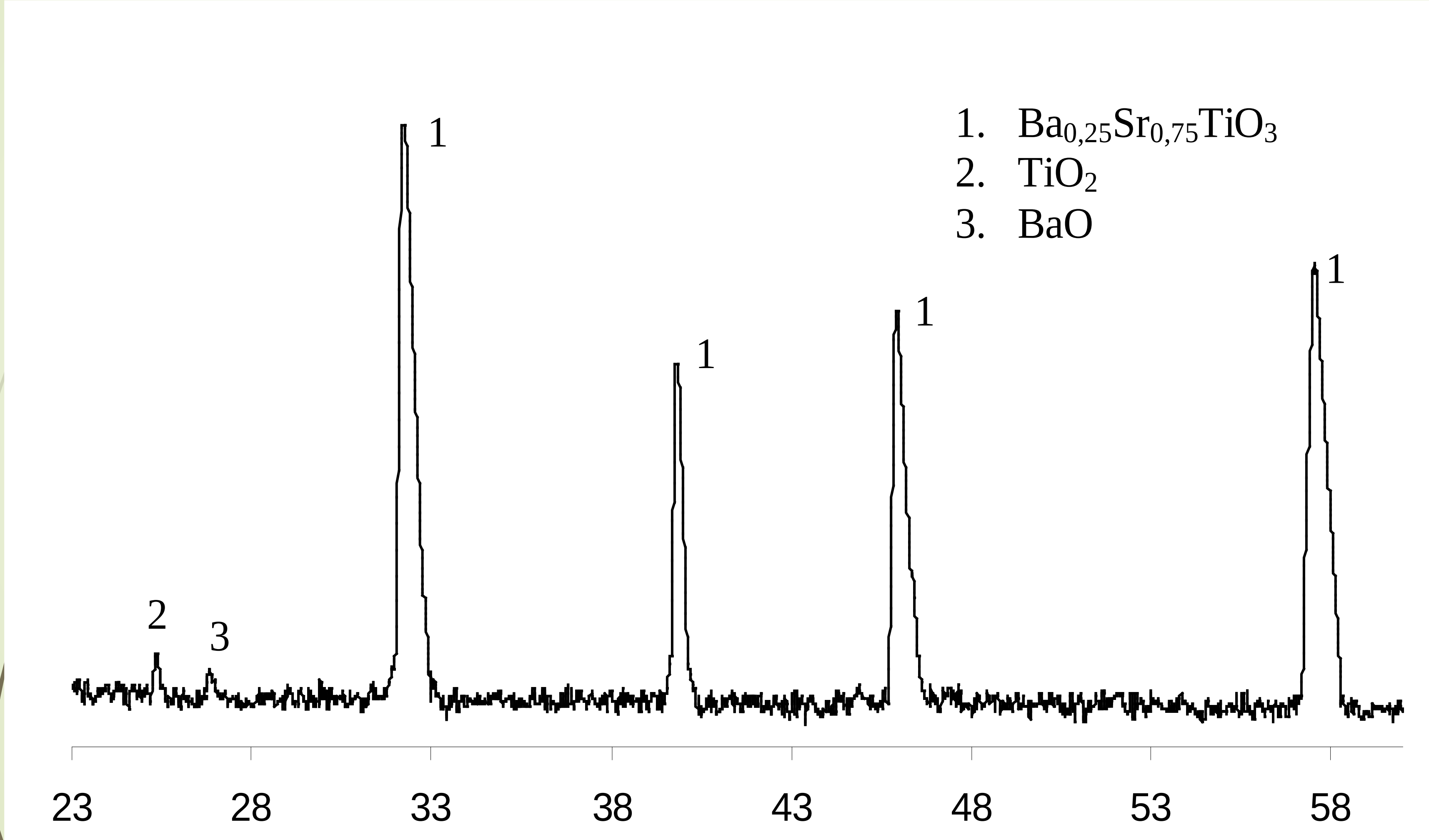
$2TiH_2 + N_2 = 2TiN + 2H_2$

$4Al + NaN_3 + NH_4Cl = 4AlN + NaCl + 2H_2$

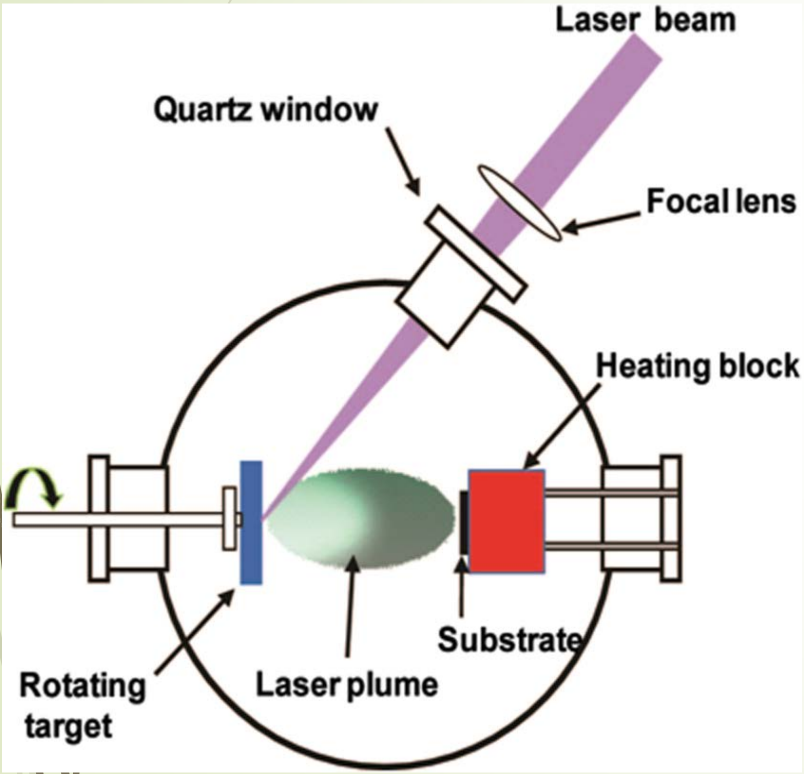
Thermal decomposition

$2BH_3N_2H_4 = 2BN + N_2 + 7H_2$

XRD Patterns of $Ba_{0.25}Sr_{0.75}TiO_3$ Powder

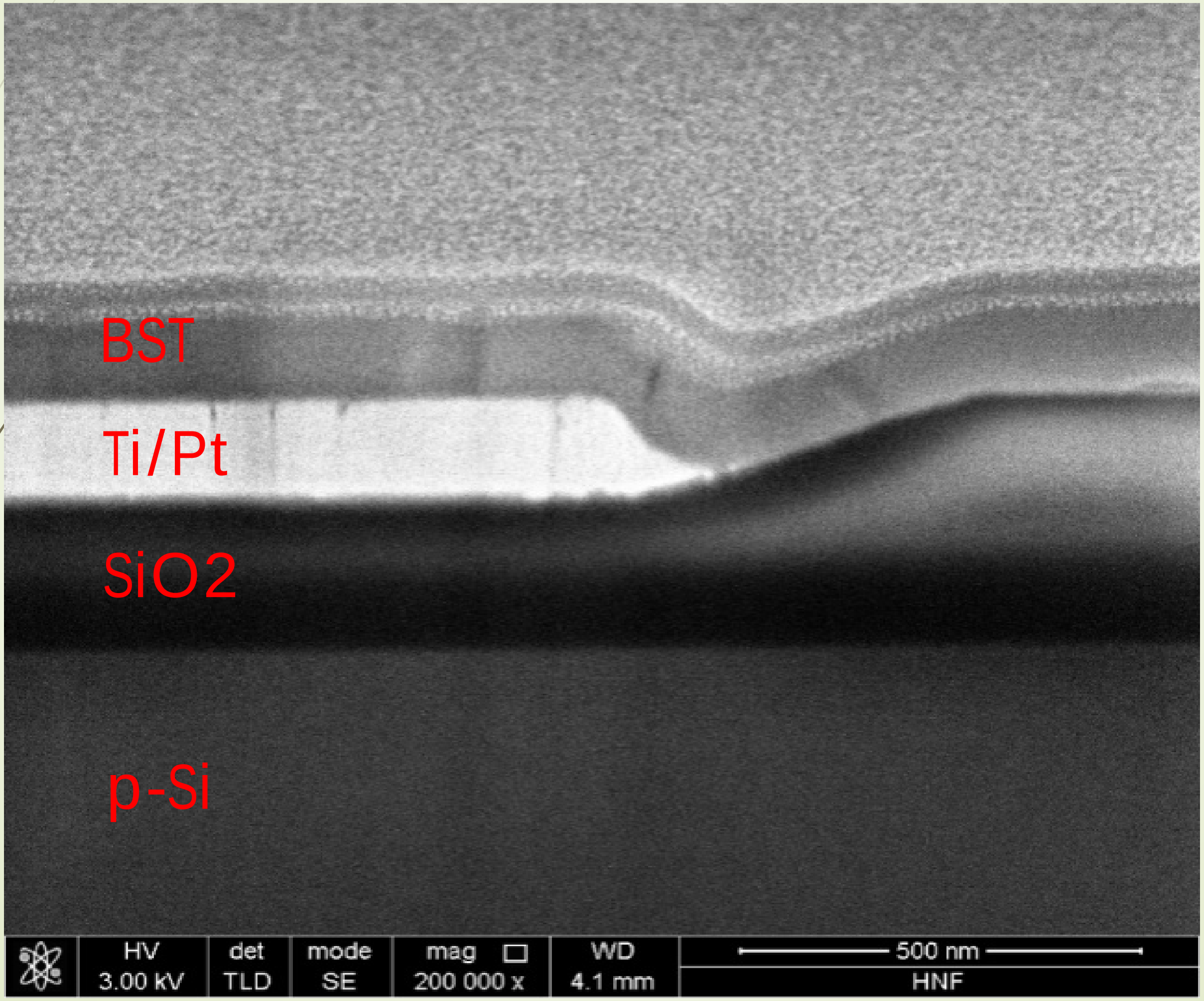


PLD of $Ba_{0.25}Sr_{0.75}TiO_3$ on a Silicon Substrate (p-Si, ρ = 1000 Ωcm)

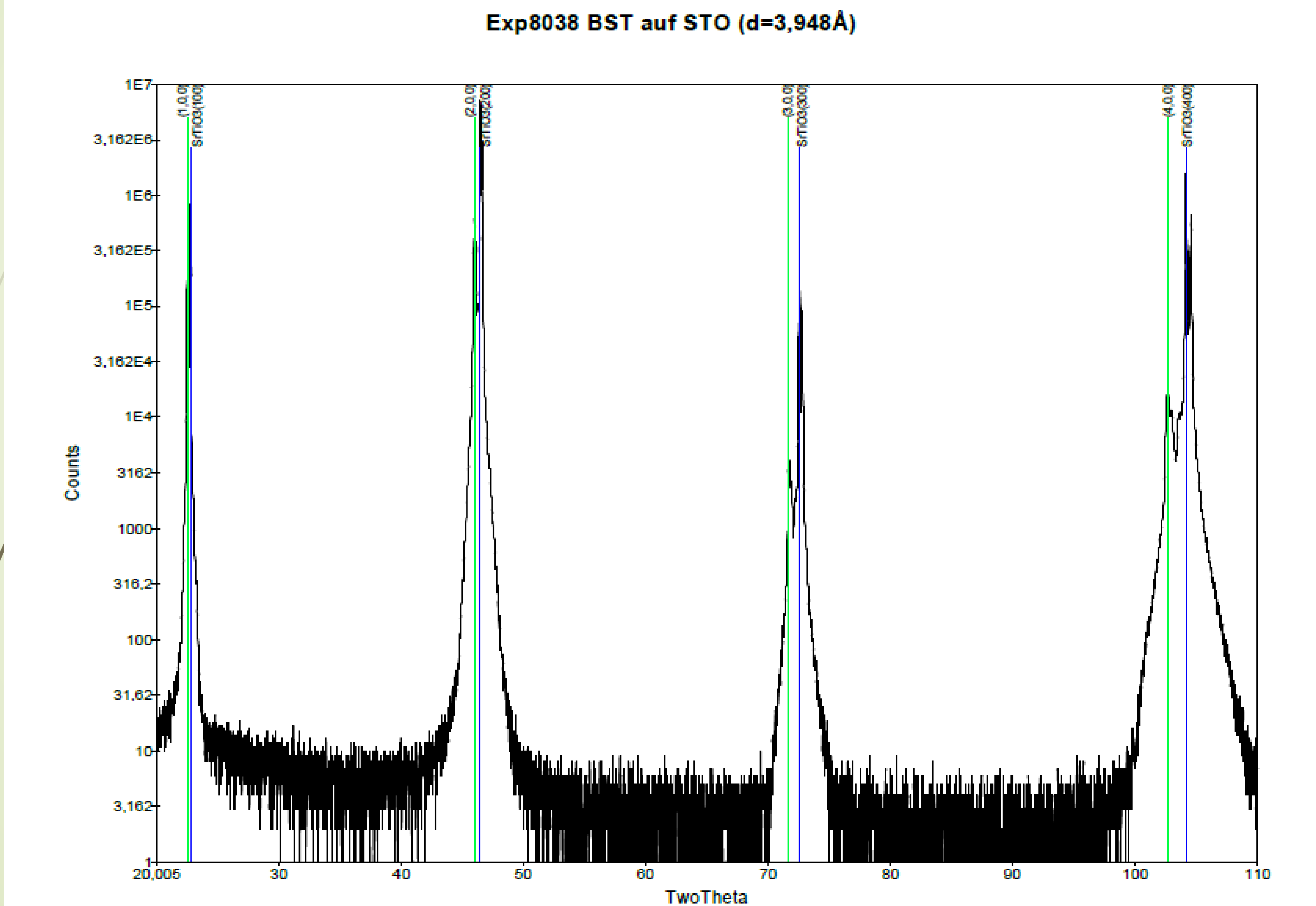


- Oxygen flow 30 mL/min, pressure $2x10^{-3}$ mbar;
- KrF-excimer laser (Lambda LPX305) with a pulse width of 20ns ;
- Pulse energy of approximately 1J per pulse;
- Energy density of $2.5Jcm^{-2}$;
- Repetition rate of 10Hz;
- Deposition time of 100s.

Cross-sectional SEM Image Showing the Si-SiO2-Ti-Pt-BST Layer Stack



XRD Patterns of $Ba_{0.25}Sr_{0.75}TiO_3$ nano-



BPM Installation and Tuning on AREAL

- Installation of BPM Hardware.
- Tuning of BPMs.
- Program development for BPM measurement observation.

Design and Programming of Hardware for Stepper Motors

- Server (on Raspberry pi), user interface and microcontroller program on arduino for Stepper motor control system.
- Program design of movement system for RF test stand.
- Hardware design for pepper pot.
- Program development for pepper pot hardware.

Prospects

- PLD station for nano layer obtainment from targets
- Topology of microdevices by microfabrication station
- Material synthesis, property optimization and characterization by X-ray radiation, gamma radiation and electron beam application
- The investigation of materials(particularly the phase structure of crystal, defects, etc.) by X-ray radiation, gamma radiation and electron beam application

Scientific Activities

- Publications
- Grants
- Workshops
- Reports

Thank You