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# HIGHLY CONDUCTING OXIDES AS SUBSTITUTION FOR TRANSPARENT CONDUCTING MATERIALS AND METAL ELECTRODES IN MICROELECTRONIC DEVICES

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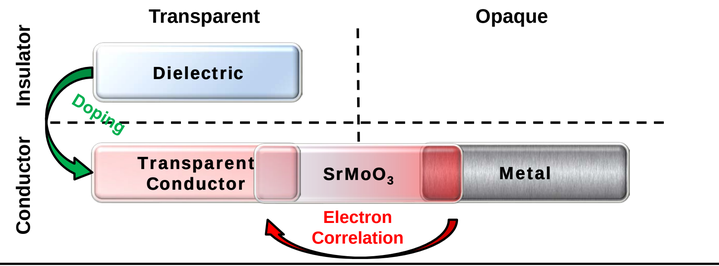
## Concept

**Design, synthesis, and study of highly conducting and optically transparent oxide materials**

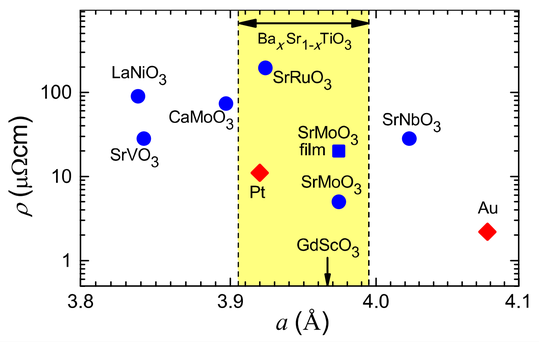
- Optically transparent oxide materials with high electric conductivity (e.g. $SrMoO_3$, $SrVO_3$, $SrNbO_3$)
- Fundamental studies of electric conductivity and optical properties
- Chemical and structural stability and compatibility with oxide functional materials (e.g. $(Ba,Sr)TiO_3$, PZT etc.)
- Minimal use of expensive and critical elements such as Au, Pt, Pd, In, etc.
- Proof-of-concept use in prototypes of microelectronic devices (e.g. all-oxide ferroelectric varactors)

### Inducing transparency in metals

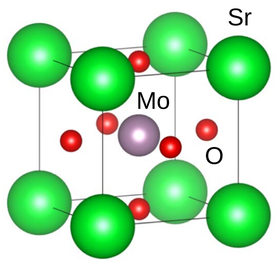



## Materials

### Highly-conducting perovskites



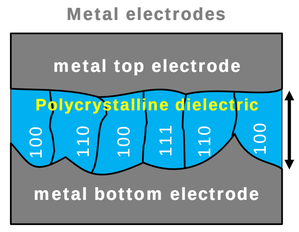

### Strontium molybdate oxide $SrMoO_3$




- Cubic perovskite structure, $a$ = 0.3975 nm
- $Mo^{4+}$ ($4d^2$, 2 electrons per f.u.)
- Electron concentration of $3\times10^{22}$ $cm^{-3}$
- Pauli paramagnetic metal ($\mu_r \sim 1$)
- ~5 μΩ cm (single crystal),
- 80 μΩ cm (ceramic)
- 20-30 μΩ cm (thin films)

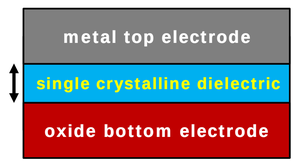
### Why highly conducting oxide electrodes?

Metal electrodes




**Polycrystalline dielectric**
- grain boundaries
- defects
- thick dielectric needed

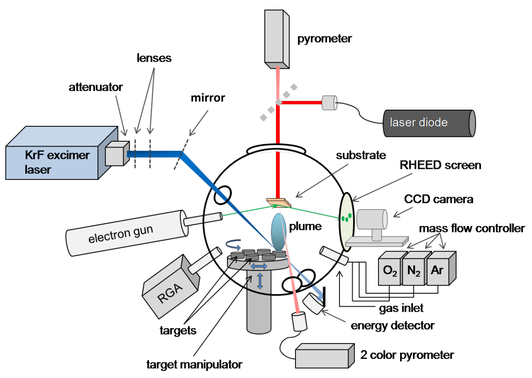
Conducting oxide bottom electrodes

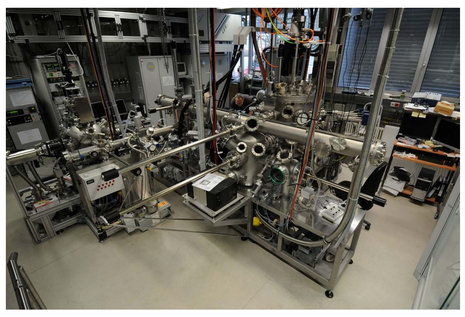



**Single crystalline epitaxial dielectric**
- lower defect density: **Low losses**
- thinner dielectric films: **Low tuning voltage**

## Characterization

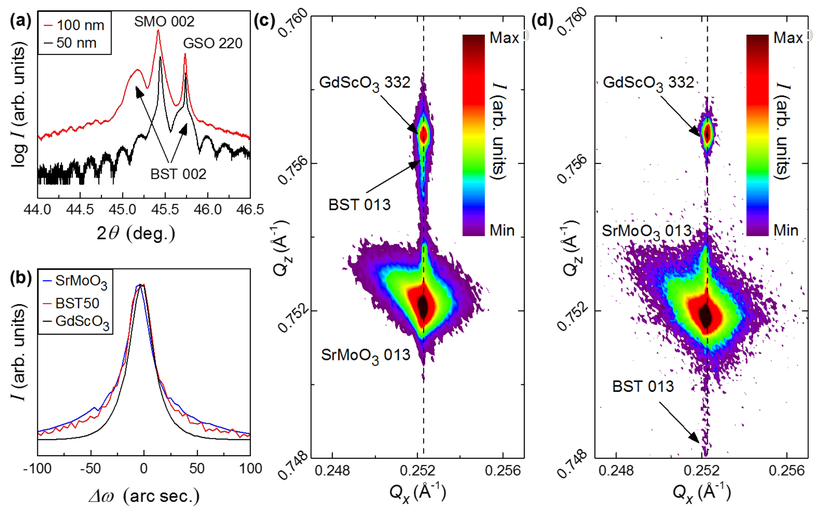
### UHV PLD and OXIDE MBE systems at MaWi, TU Darmstadt



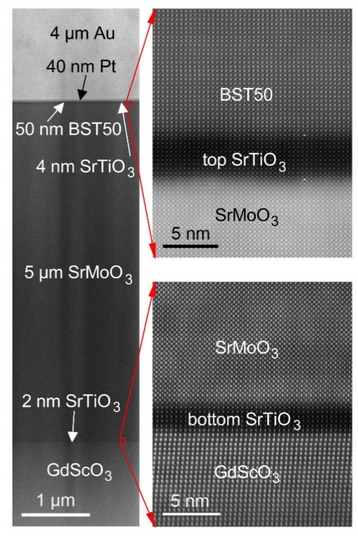



- **PLD: KrF excimer laser, laser heater**
- **6 targets, diff. pumped RHEED**
- **Sample size 10×10 mm²**
- **Oxide MBE: Radical plasma source**
- **Laser heater, diff. pumped RHEED**
- **In-vacuum sample transfer to PLD and XPS**

### BST- $SrMoO_3$ heterostructures: X-ray Diffraction




### STEM

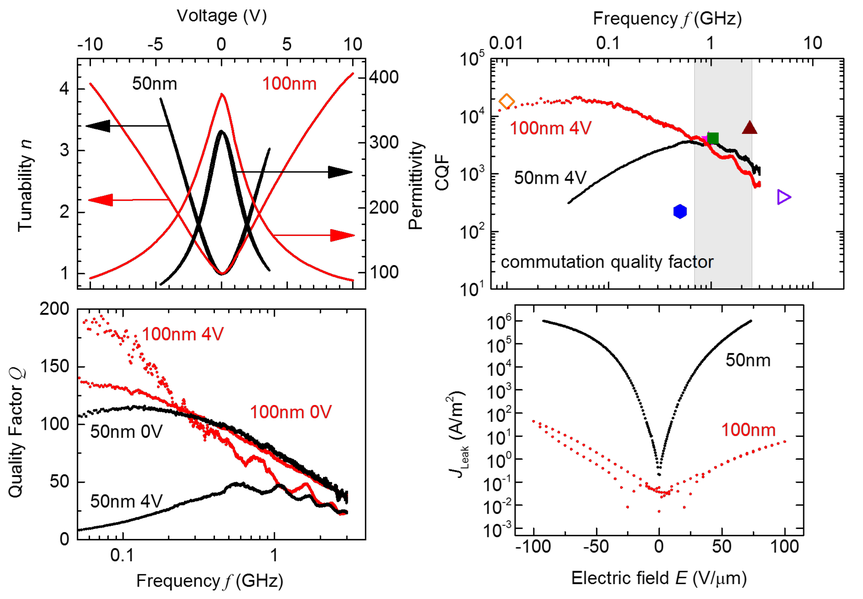



## Applications

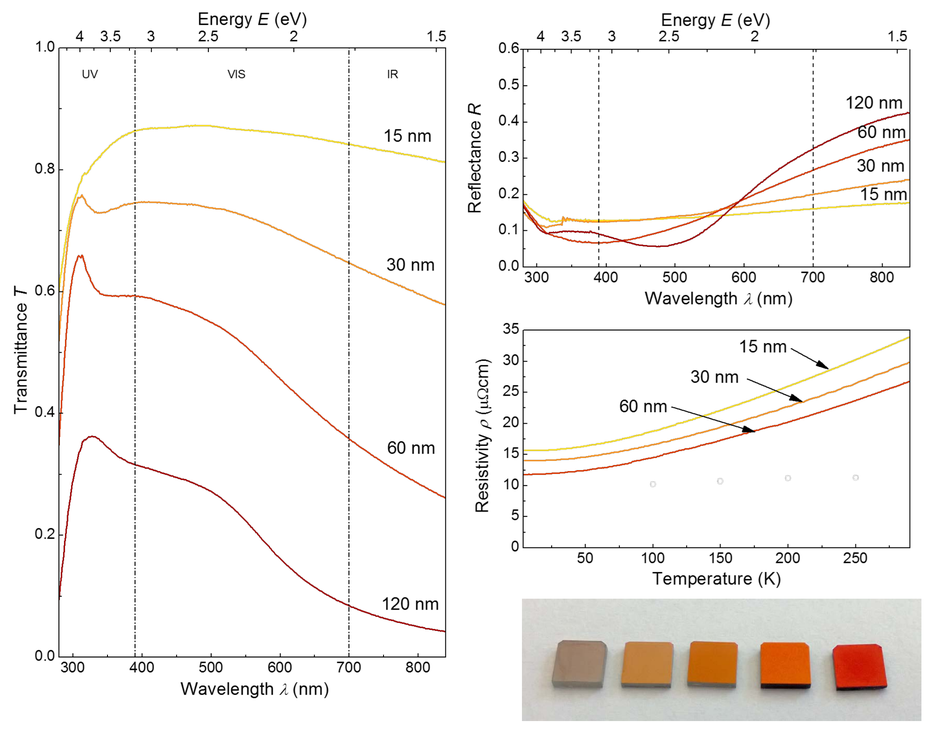
### Varactor Performance

$$n(E) = \frac{C(0)}{C(E)}$$

$$\mathrm{CQF}(E) = Q(E)Q(0)\frac{(n(E)-1)^2}{n(E)}$$




### Electric and Optical properties of $SrMoO_3$






## SUMMARY

- **Micrometer-thick, defect-free $SrMoO_3$ bottom electrodes**
- **High-performance MIM ferroelectric varactors**
- **High transmittance of more than 80% in VIS for the $SrMoO_3$ films with a thickness of only 15nm. A low sheet resistance of $R_S \approx 23$ Ω/sq.**
- **Good transmittance in IR and UV**

## CONCLUSIONS

- **For the varactors with $SrMoO_3$ electrodes, the high tunability of $n \approx 3$ at low voltage of 3.7 V (a typical voltage for Li-ion batteries!) and the high quality factor at microwave frequencies surpasses the previously reported data for the varactors with Pt electrodes**
- **THIN AND LOW-COST $SrMoO_3$ films show similar electric and optical performance as a market-leading Indium Tin Oxide $In_2O_3$-$SnO_2$ (ITO).**
- **$SrMoO_3$ IS A PROMISING SUBSTITUTION MATERIAL FOR MICROWAVE AND TCM APPLICATIONS**

**References:**

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