Room temperature Aerosol Deposition for dense ceramic coatings - functional principle and potential applications

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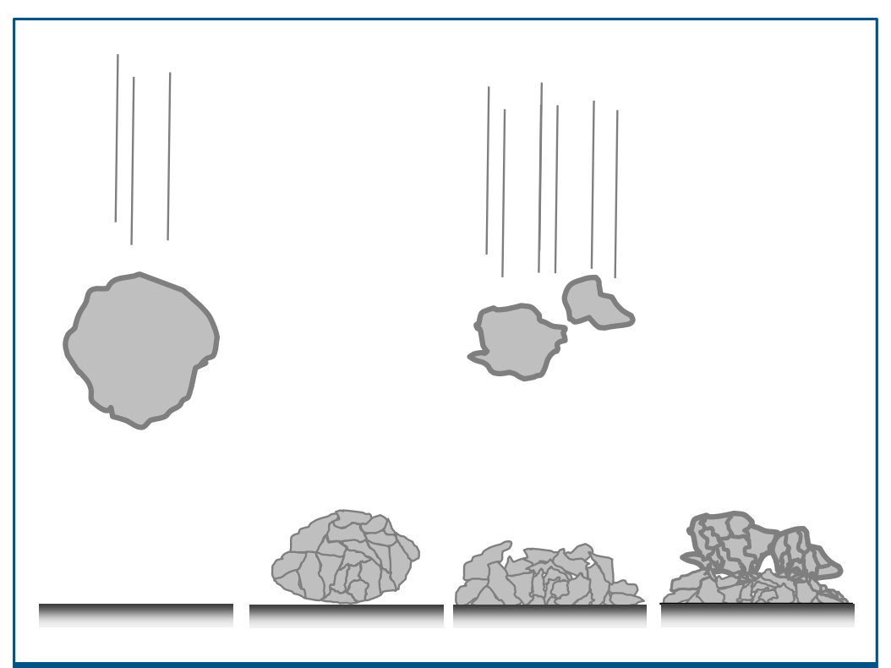
Motivation

The ***aerosol deposition*** (***AD***) method is a novel **spray coating process** for ceramic materials. With AD it is possible to obtain ***dense ceramic coatings*** at high deposition rates (several µm/min) directly from ceramic powders. Working ***at room temperature***, it makes ceramic coating technology **accessible to temperature sensitive substrate materials and applications**. This poster gives an introduction to the functional principle of AD as well as some applications. A variety of materials for different applications have been successfully deposited at the Department of Functional Materials, as shown exemplarily below.

Mechanism of film formation

Since the process happens on small scales, the mechanism for particle deposition and layer formation is difficult to analyse and has not been completely clarified yet.

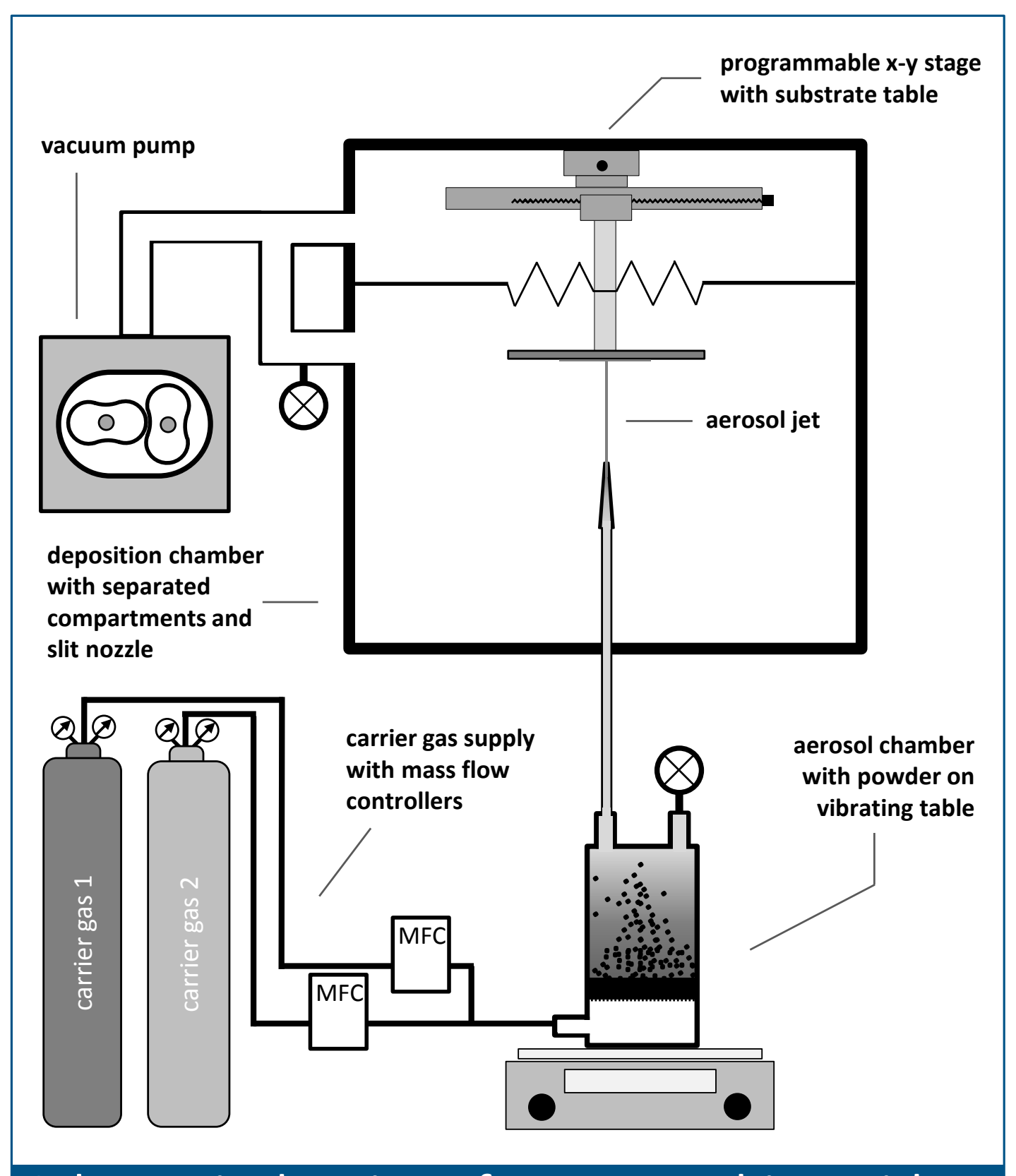


Supposed mechanism for particle fracture and consolidation

- Simulations of particle impact show local appearance of elevated temperature along with high strain in the contact area between particle and substrate [1].
- Local strain in the particle exceeds the fracture toughness and leads to ***breaking of ceramic particle*** into small crystallite fragments in the nm range [1].
- Continuous particle bombardment contributes to the ***film consolidation and growth by densification and compaction of the deposited particles*** [2].

Functional principle and setup of an AD apparatus

Ceramic particles are transported by a pressure difference into a vacuum chamber. ***Accelerated by a nozzle***, the particles ***impact on a substrate*** and form a dense layer.



Schematic drawing of an AD machine with aerosol generation unit, deposition chamber and vacuum pump

Process cycle:

- Vibration of and gas flow through the ceramic powder generates a fluidized bed.
- Carrier gas transports particles out of the aerosol chamber.
- High throughput booster pump creates a vacuum < 1 mbar in the deposition chamber.
- The pressure drop and nozzle accelerates aerosolized particles to several 100 m/s [1].
- Impact of the particles on the substrate forms a dense layer.
- x-y stage used for substrate holder allows for variable area coverage.

Parameters of influence:

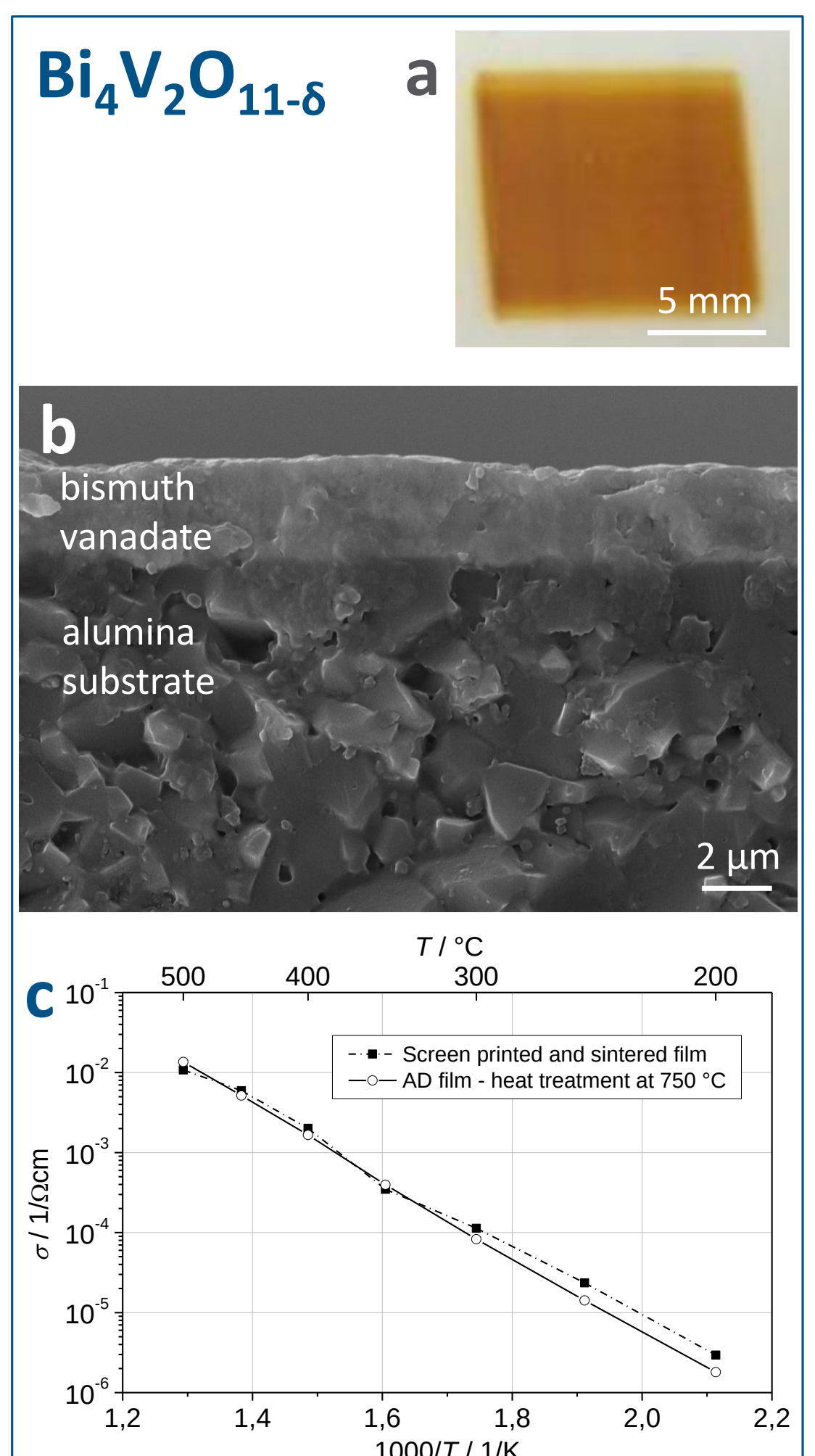
- Carrier gas (e.g. air, O_2, N_2)
- Carrier gas flow
- Particle size ($0.1 < d_{50} < 5$ µm)
- Nozzle design
- Stand-off distance

AD coatings and applications

Numerous materials such as Al_2O_3, TiO_2, Bi_2Te_3, BFT, PZT, YSZ, STF [3] etc. have been successfully deposited at the Functional Materials Department. Examples are shown below. $Bi_4V_2O_{11-\delta}$ for oxygen ion conduction. $BaFe_{1-x}Ta_xO_{3-\delta}$ ~~or~~ for sensing applications. Bi_2Te_3 for thermoelectric applications. Al_2O_3 as insulator (high resistivity) or protection layer (high hardness, inert).

Oxygen ion conductors

$Bi_4V_2O_{11-\delta}$

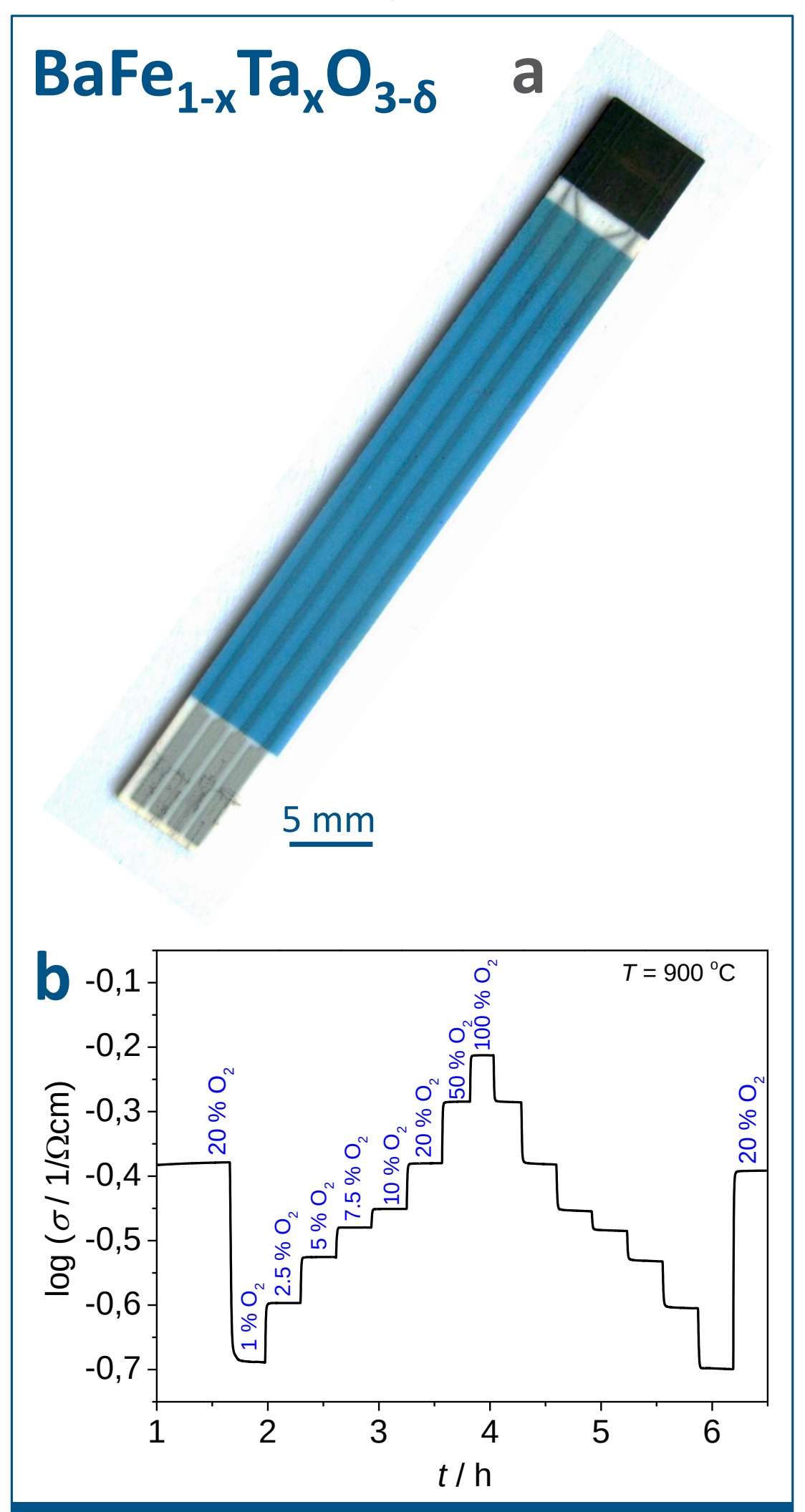


a. $Bi_4V_2O_{11-\delta}$ coating on Al_2O_3
b. SEM micrograph of fractured cross section c. Arrhenius-like conductivity plot

- Dense and homogeneous coatings achieved
- Good oxygen conductivity

Semiconducting oxides as gas sensors

$BaFe_{1-x}Ta_xO_{3-\delta}$

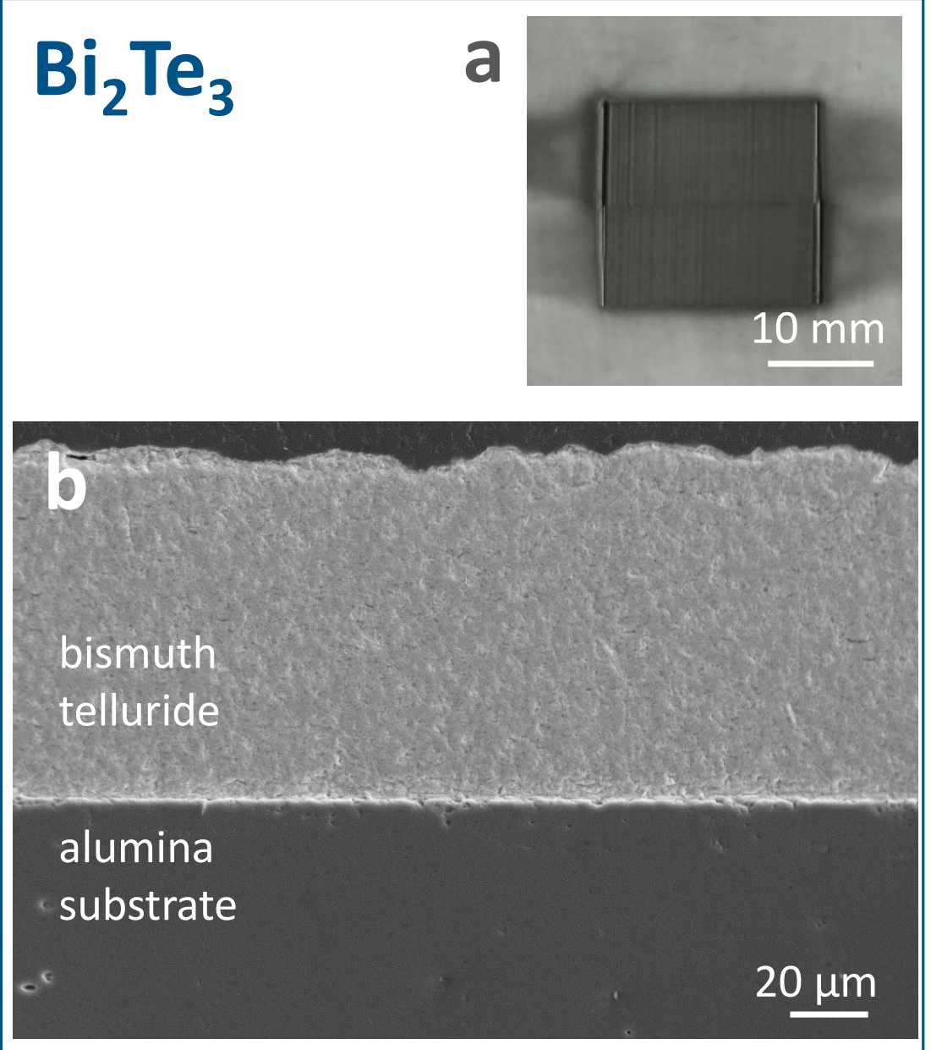


a. Coating on transducer
b. Plot of conductivity depending on the oxygen concentration [4]

- Oxygen sensing properties from 350°C up to 900°C.
- Temperature independency at high temperatures

Thermoelectric materials

Bi_2Te_3

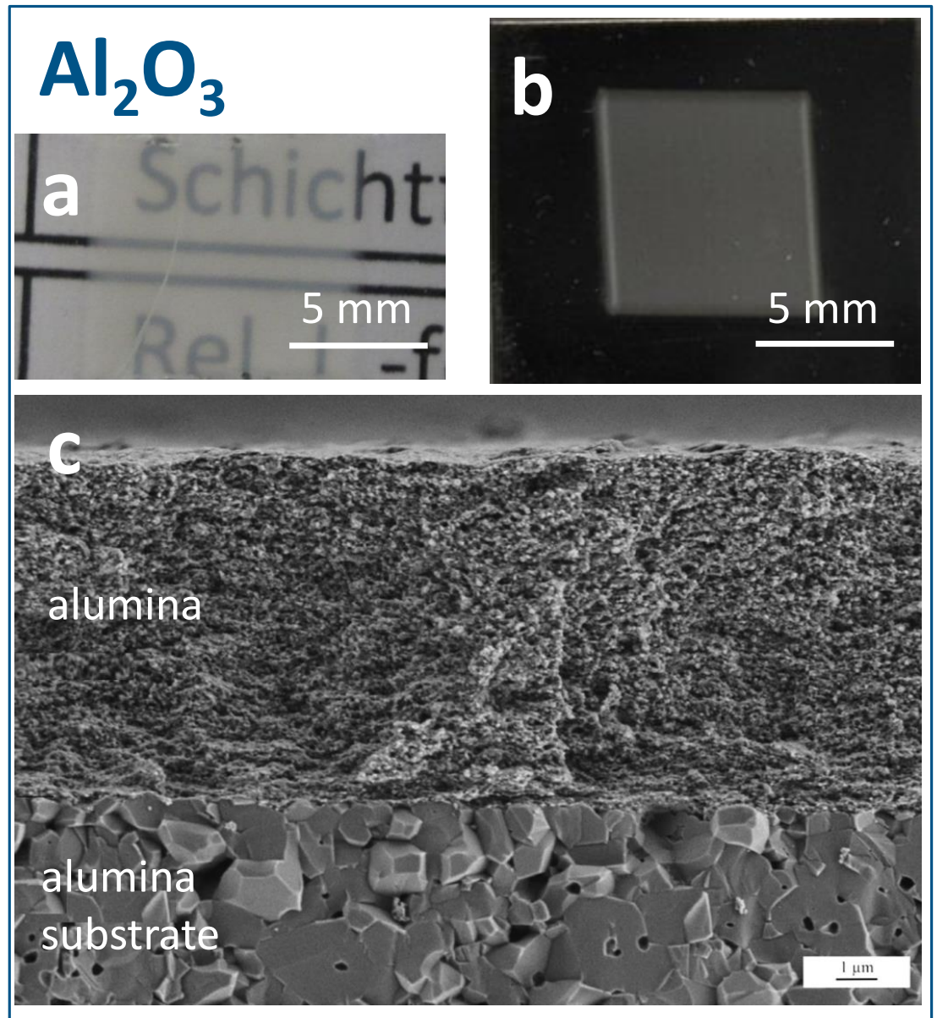


a. Bi_2Te_3 on ceramic
b. SEM micrograph of polished cross section

- Up to 200 µm thick coatings
- El. conductivity + Seebeck coefficient as in the bulk

Electrical insulation / wear resistance / environmental protect.

Al_2O_3



a+b. Al_2O_3 on glass and steel
c. SEM micrograph of fractured cross section

- Strong bond to substrate
- High transparency

AD combines several advantages:

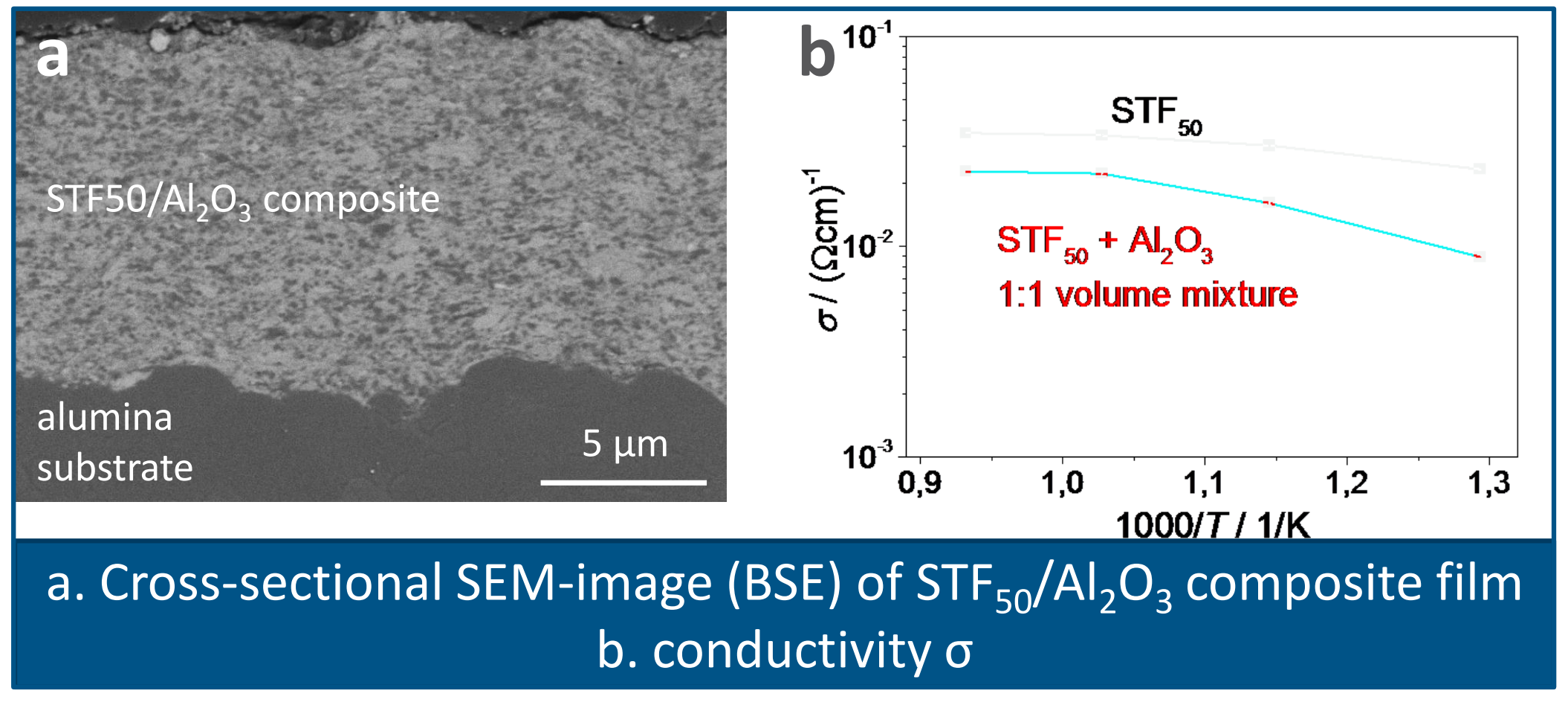
- ***Deposition at room temperature***
- ***No additional heat treatment required***
- ***Strong film adhesion to substrate***
- ***High variety of coating and substrate materials***
- ***Material properties of films close to bulk values***
- ***Only rough vacuum needed (< 10 Torr)***

Deposition of composite layers: Aerosol co-deposition of ceramics (AcDc)

Simultaneous deposition of a powder mixture: AcDc enables a further adjustment of film properties

1. Addition of a passive filler component

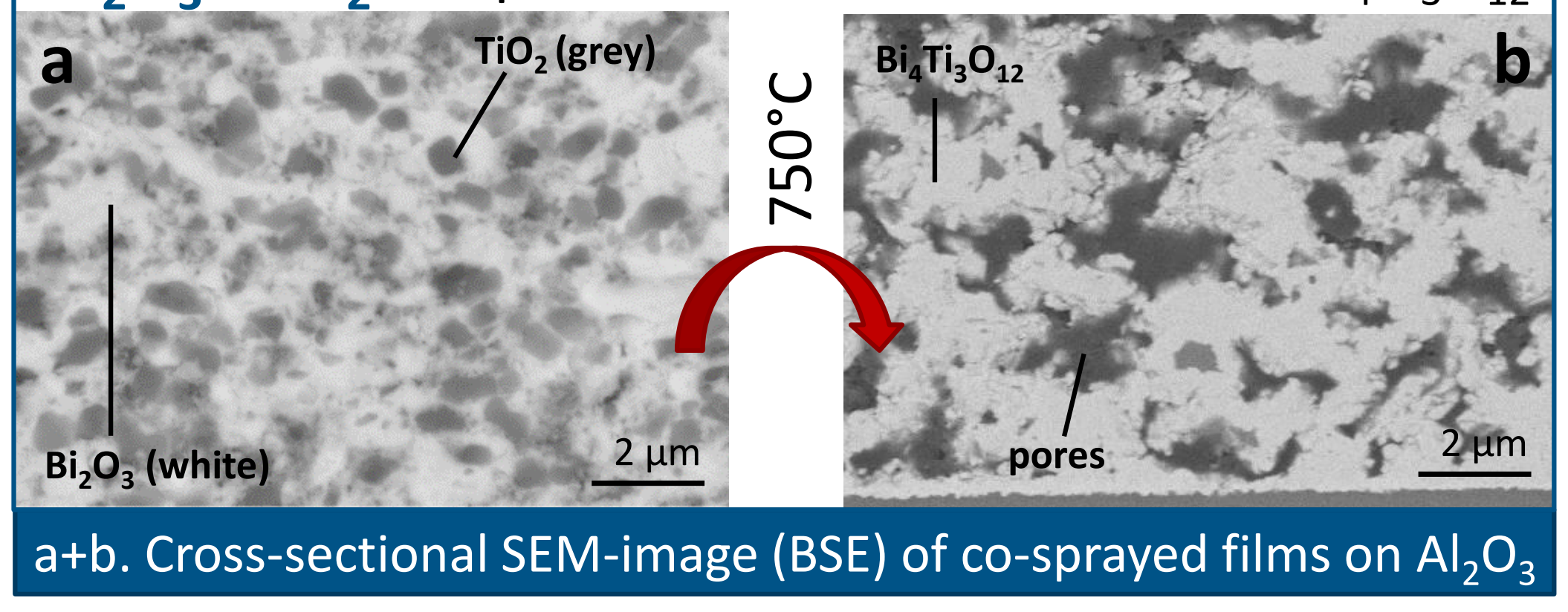
- Tune resistance of conductive ceramic films: Semiconducting STF [3] with Al_2O_3 as filler to increase *R*



a. Cross-sectional SEM-image (BSE) of STF_{50}/Al_2O_3 composite film
b. conductivity σ

2. Annealing of composite film (in-situ calcination)

$Bi_2O_3+TiO_2$ composite-film   annealed 750°C: $Bi_4Ti_3O_{12}$



a+b. Cross-sectional SEM-image (BSE) of co-sprayed films on Al_2O_3

- Annealing of composite film causes a calcination
- $Bi_4Ti_3O_{12}$ confirmed by XRD and rel. permittivity ε_r

Conclusion/Outlook

Aerosol/spray techniques can play an important role as a continuous deposition process. Since AD is a rather new method for ceramics, research in process fundamentals will be an important factor for broadening this technique to different materials and applications. Key research areas include better aerosol generation, understanding the deposition mechanism(s) and comparing resultant AD films to those from other techniques.

References

[1] Akedo, J. (2007). *Journal of Thermal Spray Technology*, 17, 181-198.
[2] Lee, D.-W., Kim, H.-J., Kim, Y.-H-, Yun, Y.-H., Nam, S.-M., (2011). *Journal of the American Ceramic Society*, 94, 3131-3138.
[3] Sahner, K., Kaspar, M., Moos, R. (2009). *Sensors and Actuators B: Chemical*, 139, 394-399.
[4] Bektas, M., Hanft, D., Schönauer-Kamin, D., Stöcker, T., Hagen, G., Moos, R.:. *E-MRS 2014 Spring Meeting*, Lille, France, May 26-30, 2014, B.IX 2.