Atomic Layer deposited thin coatings for Secondary Electron Emission yield optimization

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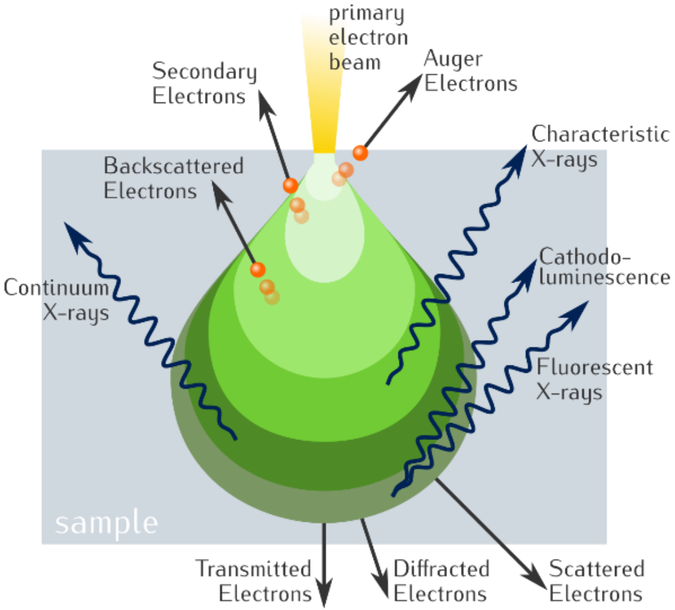
The problems induced by electronic emission yield

Electron – matter interactions



Electron – matter interactions

Peter W. Hawkes, John C. H. Spence, Springer Handbook of Microscopy, Springer Nature Switzerland AG 2019

SEEY = secondary electron emission yield => number of secondary electrons emitted by a surface for each incident electron of a given energy

TEEY = Total electron emission yield => number of secondary and backscattered electrons emitted by a surface for each incident electron of a given energy.

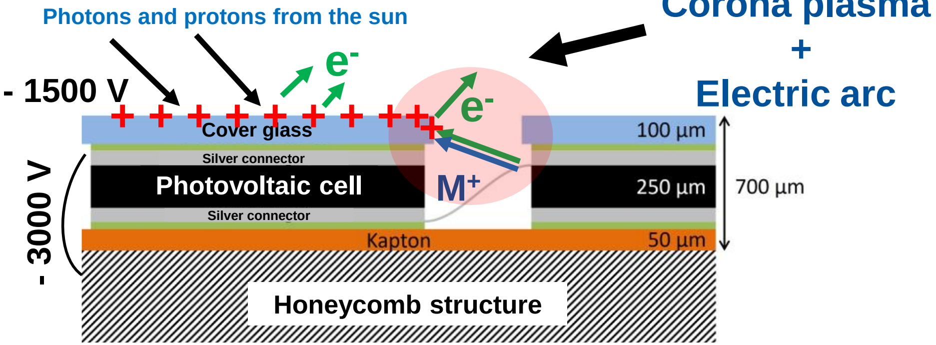
Secondary electron= low-energy electron (<50 eV) resulting from the inelastic interaction between a primary or backscattered electron and an electron in the electron cloud of one or more atoms

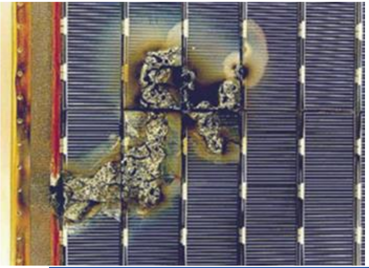
Backscattered electron= high-energy electron (>50 eV) resulting from the elastic interaction between a primary electron and the nucleus of an atom

The challenge of electronic emission yield

Electrostatic discharge on orbiting satellites

Potential difference between dielectric and conductive areas



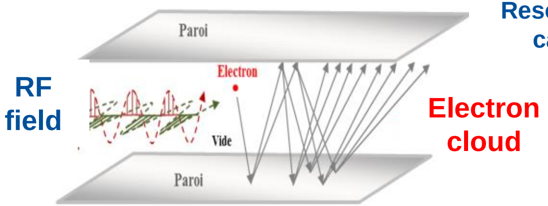


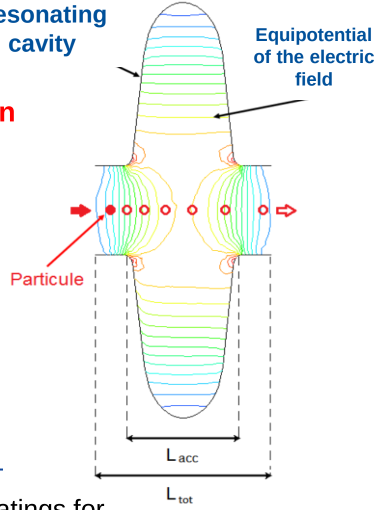
EURECA satellite solar array sustained arc, damage Credits: ESA

Multipactor Effect in RF components

Synchronisation between electronic emission and RF field

Exponential dependency on TEEY



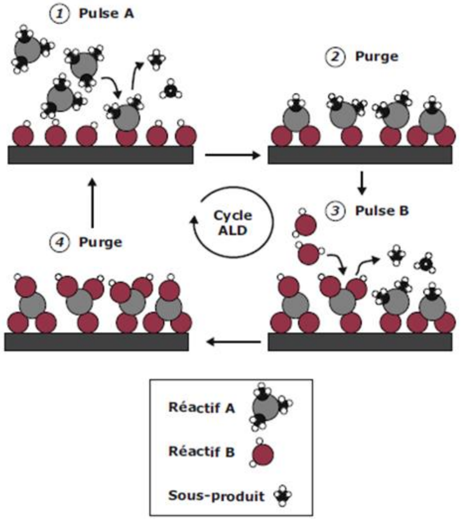


Solution :

To use Atomic Layer Deposited coatings with tunable TEEY and electrical conductivity

Atomic Layer Deposition : principes

Atomic Layer Deposition (ALD) is a chemical vapor deposition technique based on sequential self-saturating gas-surface reactions



ALD cycle reaction diagram

Advantages

Wide variety of depositable materials

Uniform coatings even on complex surfaces

Wide range of thicknesses possible

Relatively simple process control Very good repeatability

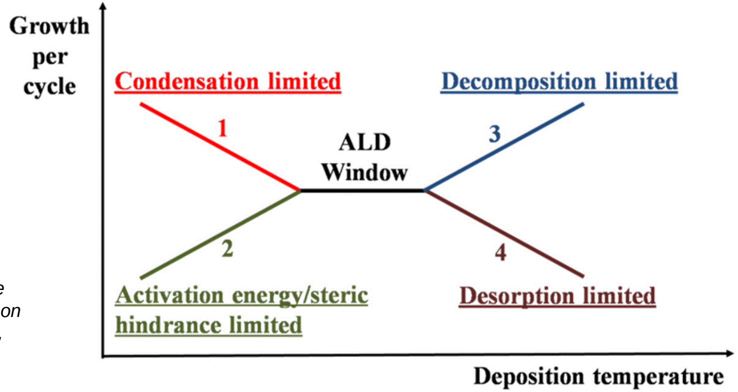
Disadvantages

Potentially very long deposition times

Variable coating properties depending on the number of ALD cycles

Need to handle hazardous reagents and reaction products

Relationship between growth rate per cycle and temperature



Yuan Qingyun et al.,*Atomic Layer Deposition of Inorganic Films for the Synthesis of Vertically Aligned Carbon Nanotube Arrays and Their Hybrids,* Coatings 2019, 9, 806

Al_2O_3 / TiN coatings for Multipacting mitigation

Yasmine KALBOUSSI

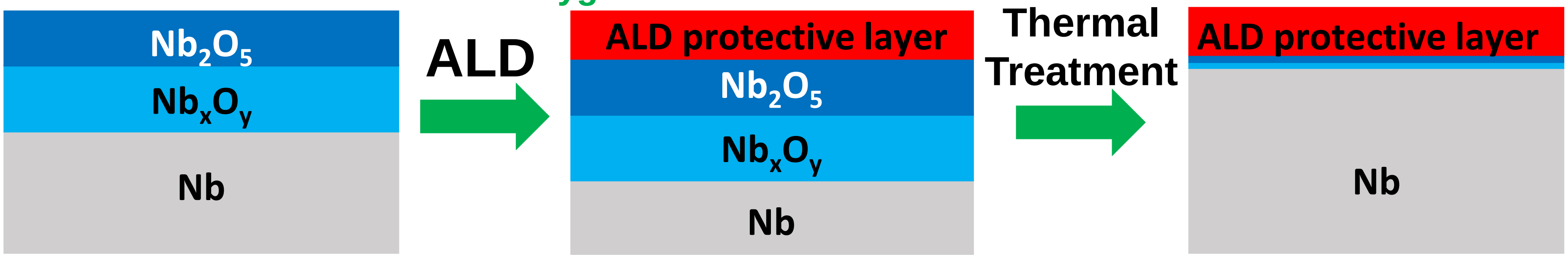
Nano hetero-structures for improving performances of Superconductors under high fields

Materials Science [cond-mat.mtrl-sci], Université Paris-Saclay, 2023

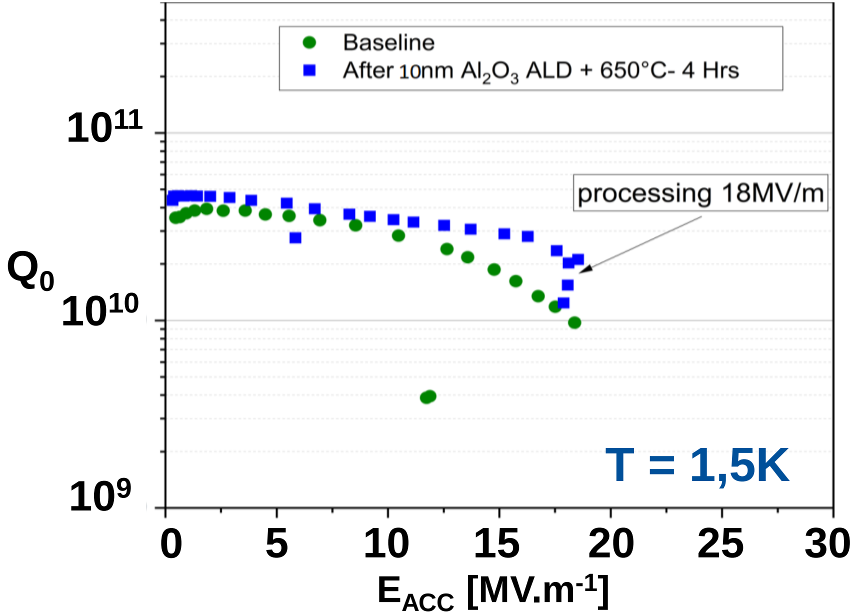
Niobium native oxyde supression

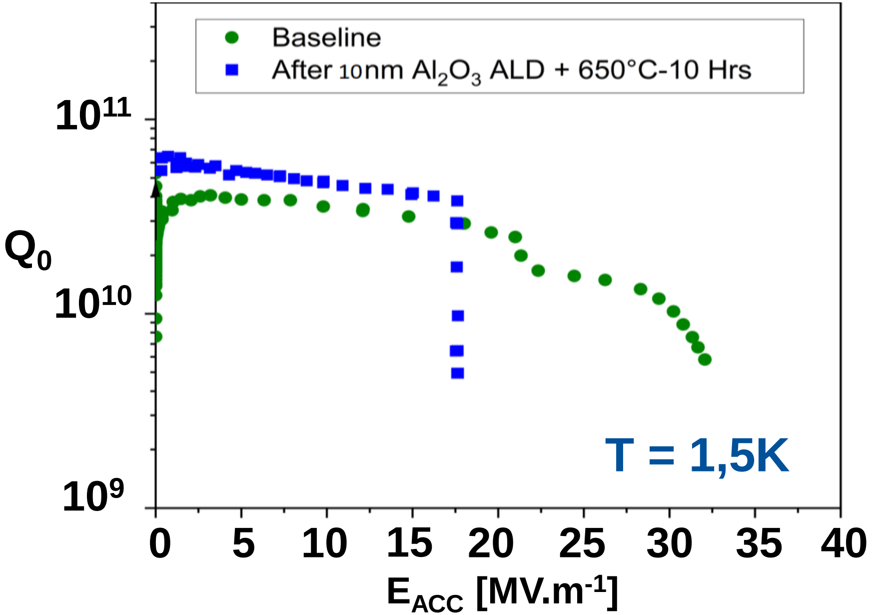
- Niobium oxidizes naturally in air
- Oxidized niobium contains impurities (two level systems) that absorb a part of the RF power
  - Leads to a diminution of quality factor
  - Limits applicable RF intensity in cavities
  - Also problematic for Q-bits application

A possible solution is to coat the oxydized niobium with a protective, low TEEY layer and then to thermal treat the coated cavity to reduced the niobium oxydes with a controled oxygen diffusion in the Nb bulk



RF test on Al_2O_3 coated Niobium cavities

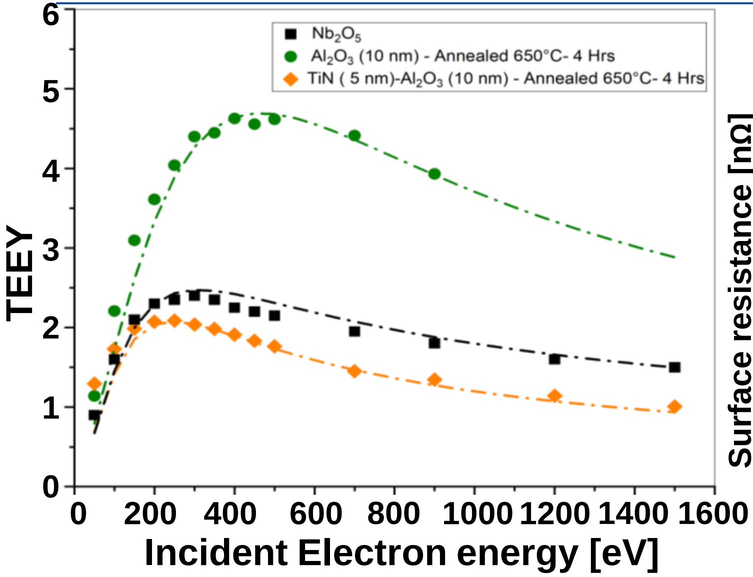


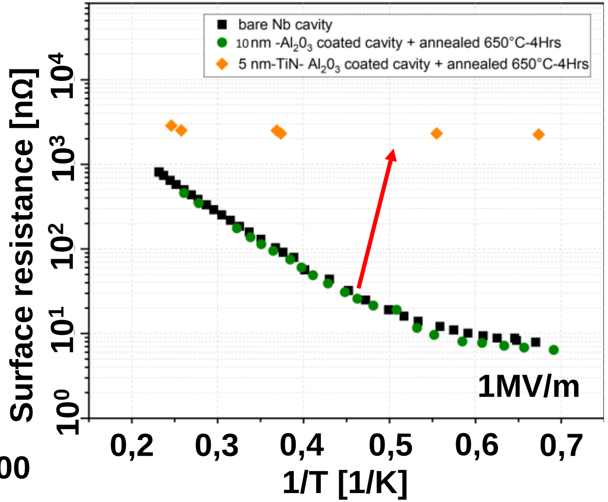


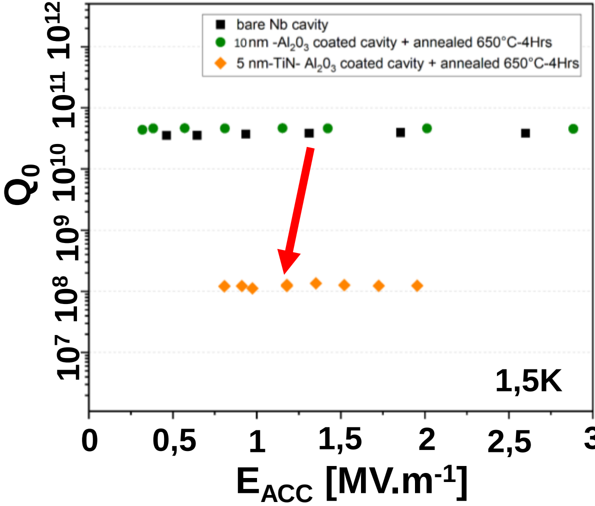
Effects of a 10nm Al_2O_3 coating on the cavity surface :

- **Improvement in quality factor for high fields**
- **Multipacting barrier at 18 MV.m^{-1}**

RF test on 5nm TiN / Al_2O_3 coated Niobium cavities





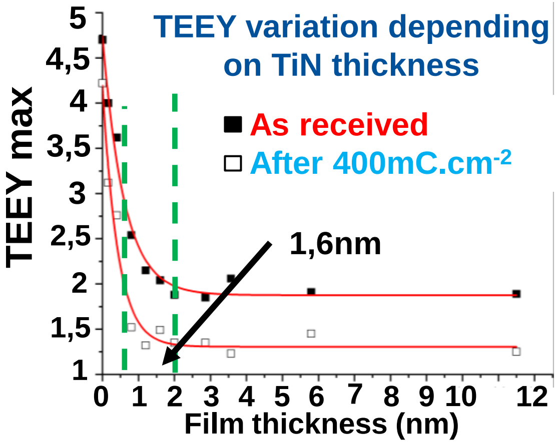


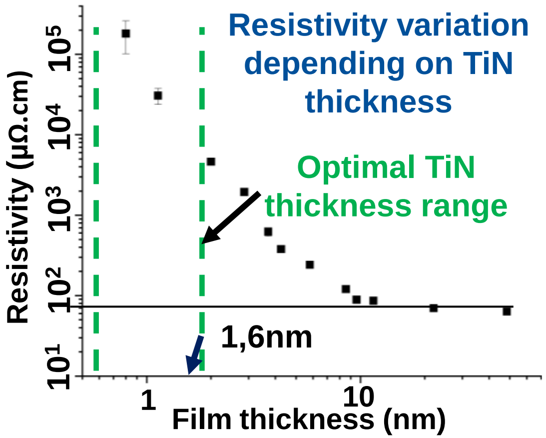
Effects of a 5nm TiN coating:

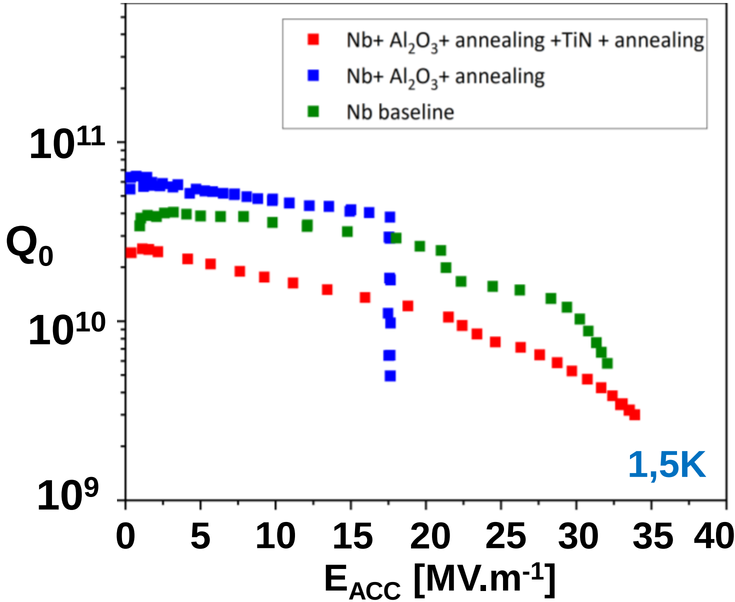
- Reduction of the TEEY on Nb samples
- Significant reduction of the quality factor on cavities

An optimum TiN thickness must be found to reduce TEEY without increasing surface resistance.

Effect of 40 ALD TiN cycles on Al_2O_3







Parameters for exponential d_0 fits $y = y_1.e^{-d/d0}+y_0$			
	y_1	d_0 [nm]	y_0
As deposited	2.8 ± 0.1	0.60 ± 0.06	1.87 ± 0.06
After conditioning	2.9 ± 0.2	0.42 ± 0.06	1.30 ± 0.07

Effects of a 1,6nm TiN coating on the cavity surface :

- **No Multipacting barrier**
- **Acceptable reduction of the quality factor for some particle accelerators.**

Under review J. of applied physics

Can TEEY and electrical conductivity be modulated according to chemical composition and coating structure?

Multilayered ZnO/MgO coatings for electronic emission yield and electrical conductivity optimisation

Multilayred ZnMgO coatings : introduction

- **ZnO :**
  - **- SEEY = 2**

    Xiangping Zhu et al., *Theoretical and experimental investigation of secondary electron emission characteristics of ALD-ZnO conductive films*, J. Appl. Phys. 128, 065102 (2020)

  - **- Conductivity = 7,1 10^{3} $\Omega^{-1}.m^{-1}$**

    W.J. Jeong et al., *Preparation and characteristic of ZnO thin film with high and low resistivity for an application of solar cell,* Thin Solid Films 506 – 507 (2006) *180 – 183*

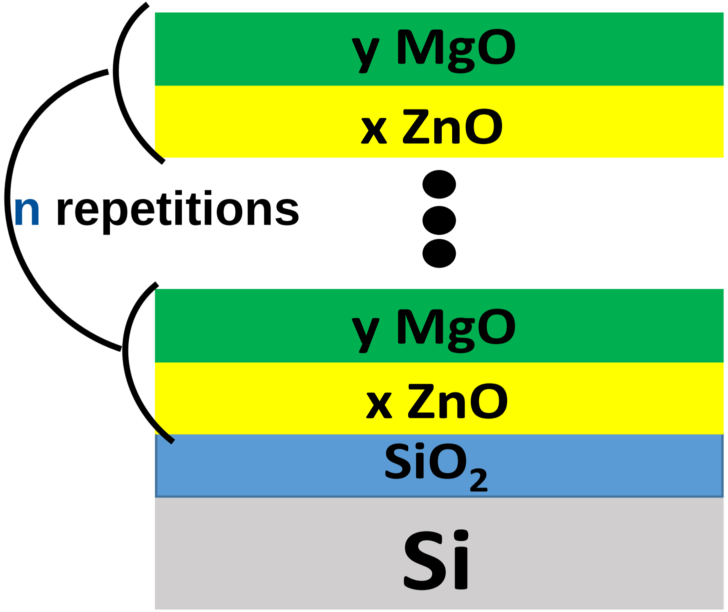
- **MgO :**
  - **- SEEY = 6,2**

    J. Guo, et al., *Theoretical and experimental investigation of secondary electron emission characteristics of MgO coating produced by atomic layer deposition* ,Ceramics International 46 (2020) 8352–8357

  - **- Conductivity = 10^{-15} $\Omega^{-1}.m^{-1}$**

    H. KATHREIN and F. FREUN,*Electrical conductivity of magnesium oxide single crystal below 1200 K*, J. Phys. Chem. Solids Vol 44. No. 3. pp 177-186. 1983

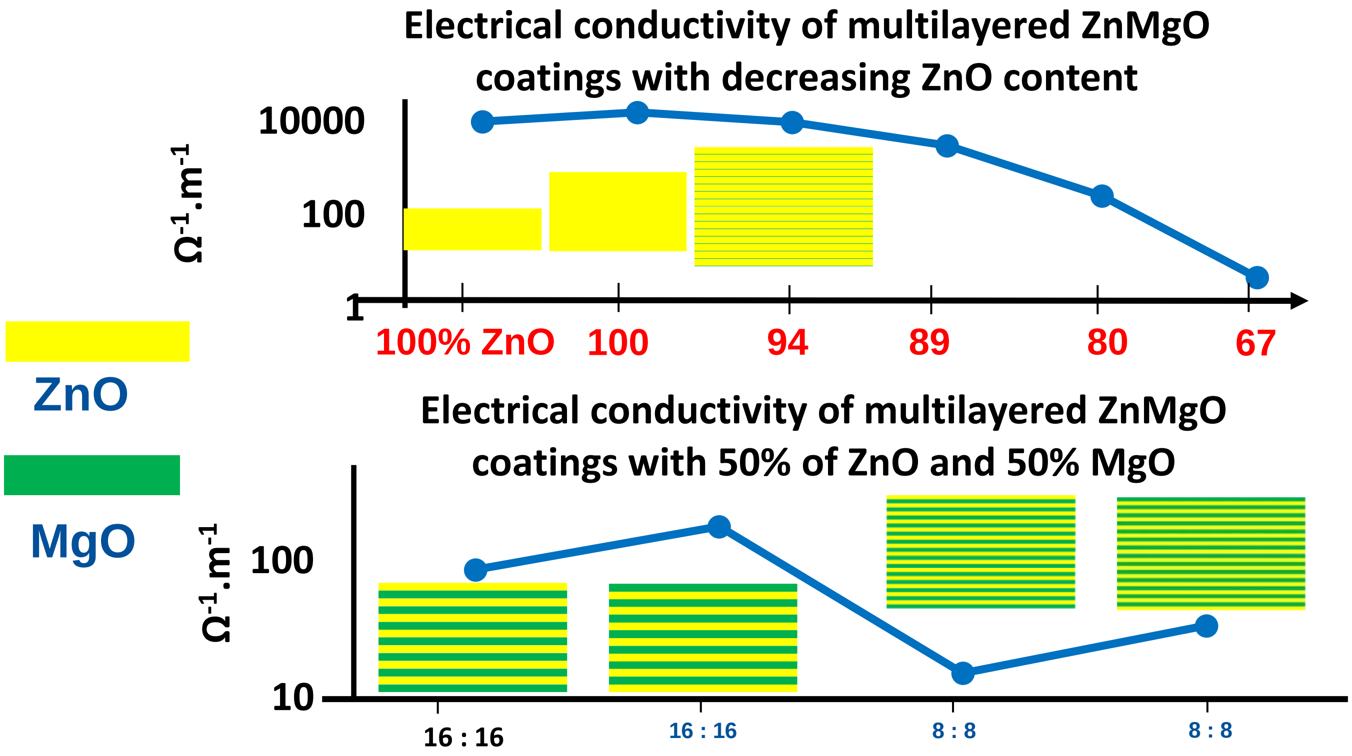
- **Common properties :**
  - Metallic oxydes
  - Chemically stable
  - good transparency in the visible range
  - Similar Growth Per Cycle



schematic diagram of a multilayer coating

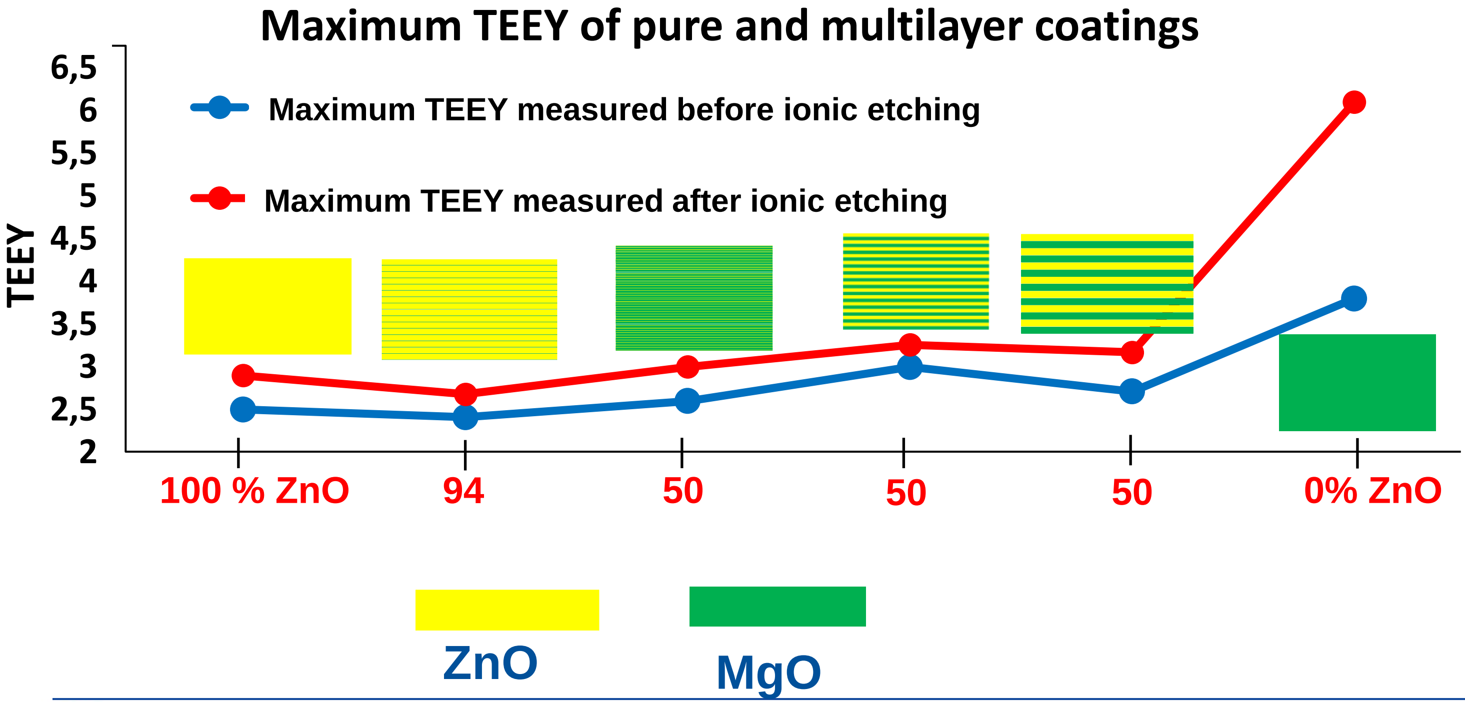
x ZnO / y MgO x n

Multilayered ZnMgO coatings : conductivity



The chemical composition and stacking structure of materials can modulate the coating conductivity

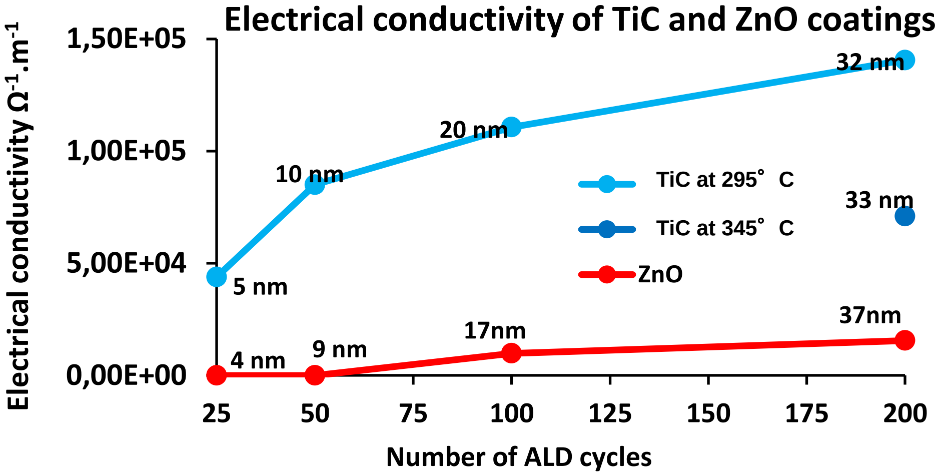
Multilayred ZnMgO coatings : TEEY

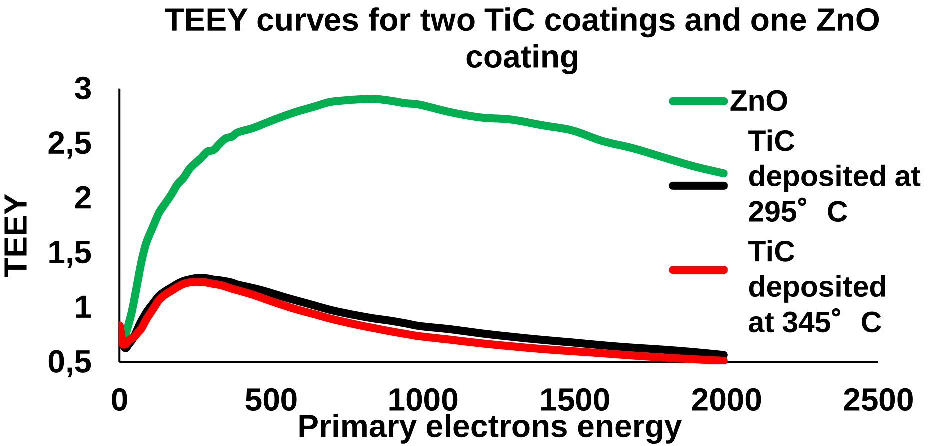


The chemical composition and stacking structure of materials can modulate the TEEY

To extend the range of TEEY and electrical conductivity modulation, we need a new material to replace ZnO as

TiC : Electrical conductivity and TEEY





Very interesting TEEY and electrical conductivity properties
but
Need for a replacement for MgO to avoid TiC oxidation

We will replace MgO with MgF_2

TEEY and electrical conductivity equivalent to those of MgO

No source of oxidation in the synthesis

Conclusion

- **Multilayer coatings based on ZnO and MgO show that electrical conductivity is tunable depending on chemical composition and structure; initial measurements after removal of adventitious carbon seem to indicate a similar tendency for TEEY**

- **By choosing TiC and MgF_2 respectivly to replace ZnO and MgO as a new couple of materials with a higher gradient of electrical conductivity and TEEY, it should be possible to produce a new coating, with an extended property range that will be interesting for orbiting satellite and RF components applications**

Atomic Layer Deposition : Alumina synthesis