Institut de Recherche de Chimie Paris

ALD deposition of Er and Eu-doped yttrium oxide thin films for quantum technologies

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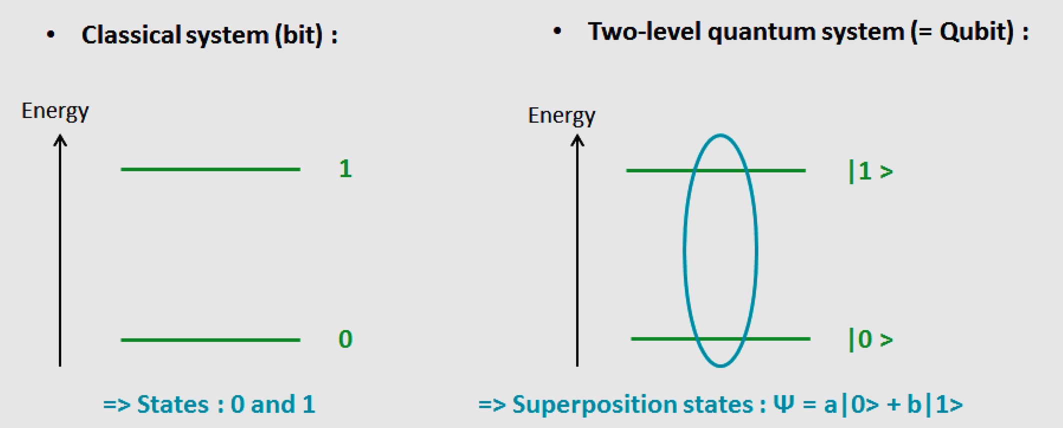
Introduction

- Quantum technologies = new disruptive technologies for many applications
- Based on the **superposition states**
- Work well with **rare earth single crystal**

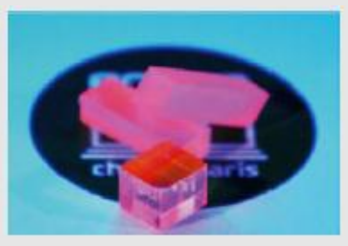


- Quantum information limited by the problem of **decoherence** due to interactions with the environment
  → Loss of quantum information
- Materials needed with **long coherence lifetimes** (high T_2)

Materials choice = $Y_2O_3:Er^{3+}$ and $Y_2O_3:Eu^{3+}$ thin films:

- Rare earth ions:
  - 4f orbitals protected from the outside => **particular optical properties**
  - Advantage for **doping**: Y can be substituted by any kind of rare earth
- Need for **a host material Y_2O_3**:
  - Chemical compatibility
  - Er^{3+} and Eu^{3+}: can be interchanged with Y^{3+}
  - Low nuclear spin contact

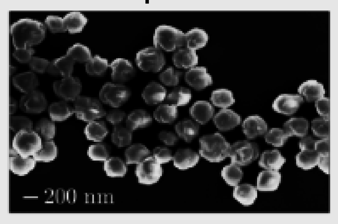
Monocrystal



State of the art for $Y_2O_3:Eu^{3+}$:

- Monocrystal : **T_2 ≈ 1 ms**
- Transparent ceramic : **T_2 ≈ 100 µs** (1)
- Nanoparticles : **T_2 ≈ 7 µs** (2)

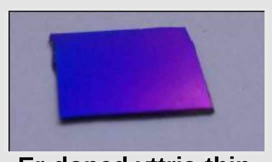
Nanoparticles



→ Effect of the structuration on coherence properties ?

Goal

- **NanOQTech project:** development of rare earth doped nanostructures for hybrid quantum systems
- Elaboration and investigation of **properties of $Y_2O_3:Eu^{3+}$ and $Y_2O_3:Er^{3+}$ thin films** on silicon substrates:
  - Properties at the nanoscale ?
  - Integration in devices based on planar geometry of films
  - Coupling with others systems
- **Final goal =** obtain a high quality very thin film with properties as close as possible to the single-crystal

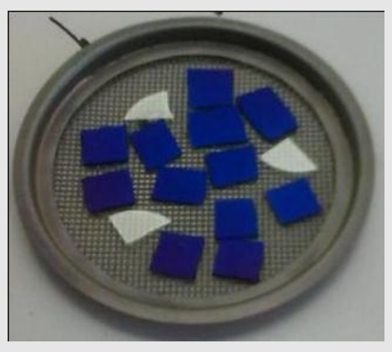


Er-doped yttria thin films (300 nm in thickness)

NanOQTech http://www.nanoqtech.eu/

Experimental procedure: Atomic Layer Deposition (ALD)

- Method for depositing thin layers in **gas phase**, based on **interactions** with the surface
  → Atomic level control

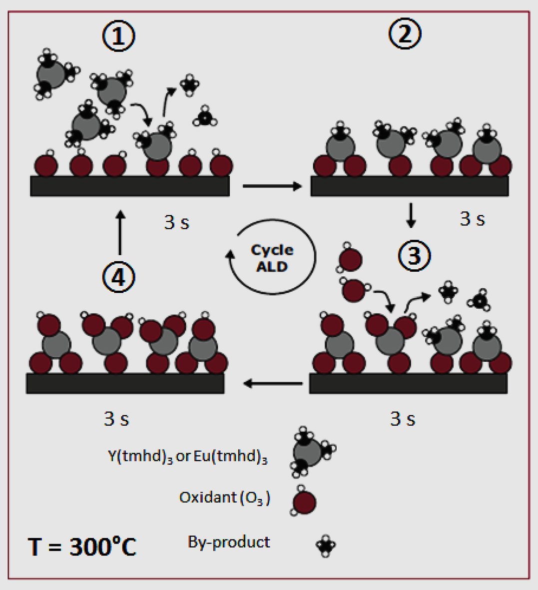


Example of a deposition made with ALD method on Si(100) and fused silica substrates

- Advantages :
  - **High conformality** → well-suited for complex architecture
  - **Thickness control** very precise and **very homogeneous** deposition
  - **Self limited growth** in ALD temperature window
- Drawbacks :
  - **Slow deposition rate** (≈ 0.2 – 0.3 Å/cycle)
  - **Low temperature** (T < 600° C) => hard to well-crystallize
  - **Carbon contamination** from ligands

- Principle = the repetition of an **"ALD cycle"** => sequential method

(3)



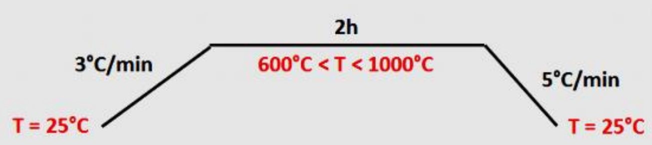
① $Y(tmhd)_3$ / $Er(tmhd)_3$ / $Eu(tmhd)_3$ pulse

② N_2 purge

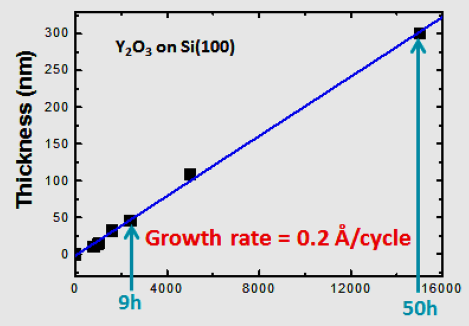
③ Ozone pulse

④ N_2 purge

Annealing step after deposition



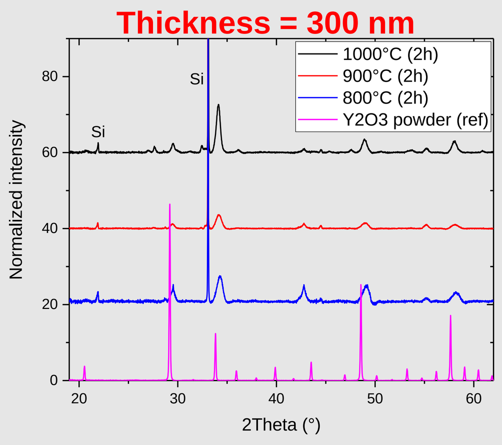
=> Number of ALD cycles α thickness



Results concerning $Y_2O_3:Er^{3+}$ thin films

XRD

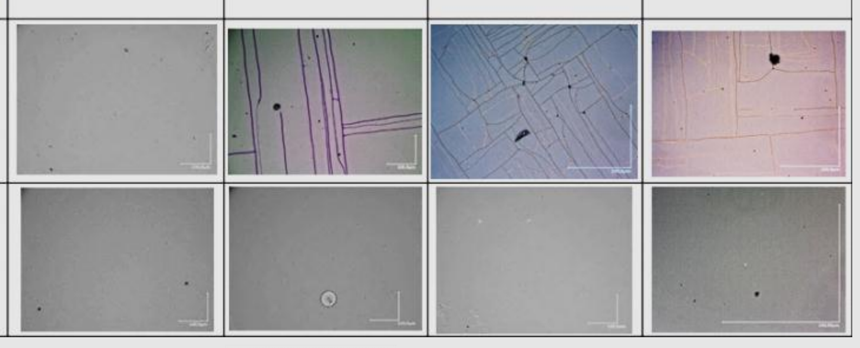
Thickness = 300 nm



→ Slight improvement of crystallinity with the annealing temperature

Optical microscopy

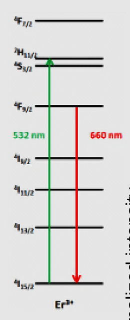
Substrate and thickness	As-deposited	600°C (2h)	700°C (2h)	800°C (2h)
Si(100) 300 nm				
Si(100) 100 nm				

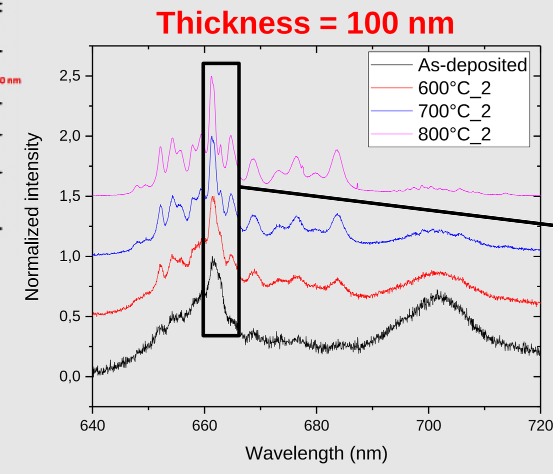


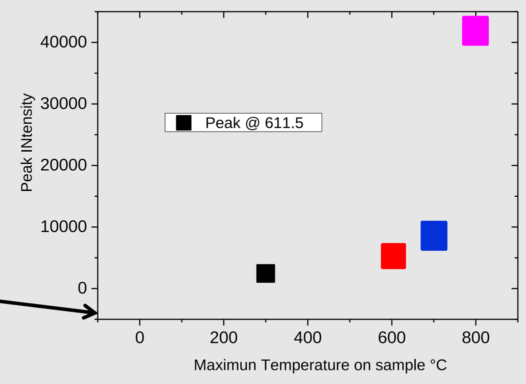
→ Cracks increase with the annealing temperature and disappear when the thickness decreases

Microfluorescence

Thickness = 100 nm



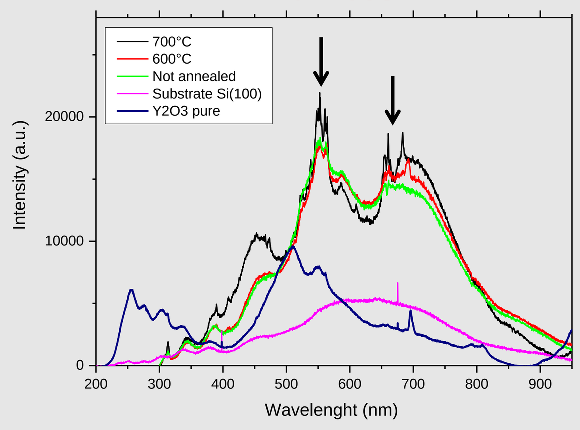




→ Fluorescence emission intensity increases and peaks become narrower with the annealing temperature

Cathodoluminescence

Thickness = 11 nm

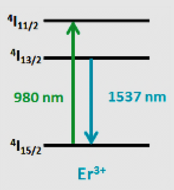


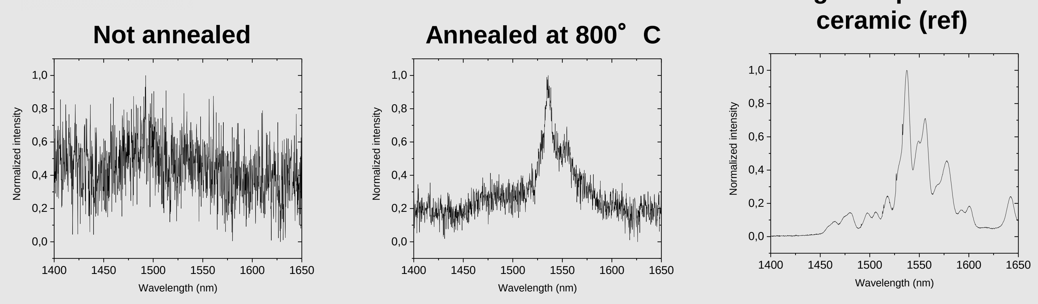
→ Fluorescence emission is visible on very thin films

→ Peaks become narrower with the annealing temperature

IR-range fluorescence emission

Thickness = 300 nm



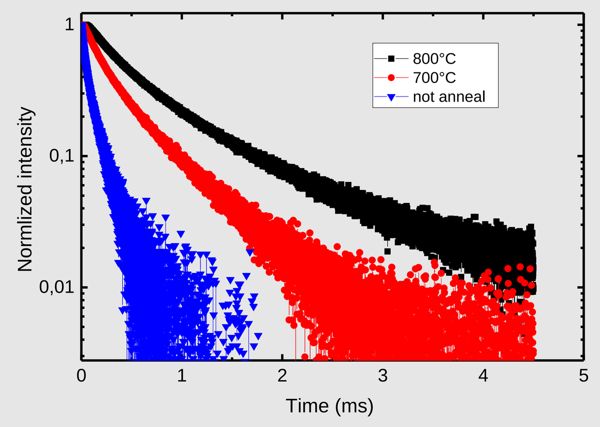


→ Same shape between reference and sample annealed at 800° C

→ Emission peak intensity increases with the annealing temperature

Lifetime measurements

Thickness = 300 nm



Sample	Ceramic (ref)	Not annealed	700°C (2h)	800°C (2h)
T_1	8 ms	0.1 ms	0.3 ms	1 ms

→ Lifetime decay increases with the annealing temperature

→ These measurements confirm microfluorescence results

Conclusions

- The $Y_2O_3:Eu^{3+}$ and $Y_2O_3:Er^{3+}$ thin films on silicon substrates synthesized by ALD with thickness between 11 and 300 nm are **crystallized**
- An **annealing step** after the deposition seems to be indispensable to improve optical spectroscopic properties of the material
- **Perspective :** improving thin films quality to couple with graphene for example (4)

References

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