
# Oxide nanosheets as seed layers for growth of complex oxides on Si and glass

**ISCR, Rennes:** F. Baudouin, S. Gaddour, M. Barrabe, S. Ollivier, M. Chettab, S. Députier, M. Guilloux-Viry, V. Demange

**CRISMAT, Caen:** A. Boileau, M. Dallocchio, A. David, U. Lüders, W. Prellier, A. Fouchet

**GEMaC, Versailles:** B. Bérini, Y. Dumont

**P', Poitiers:** S. Hurand

# Oxide thin films

**Functional oxides:** **ferroelectricity, ferromagnetism, multiferroism, electric conductivity, ionic conductivity, electro-optics, catalysis ...**

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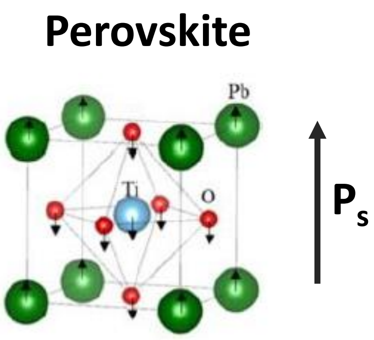


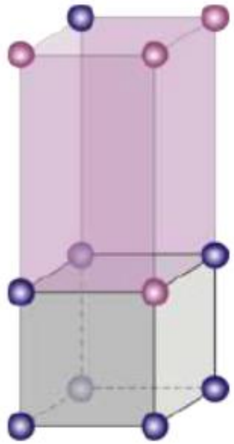

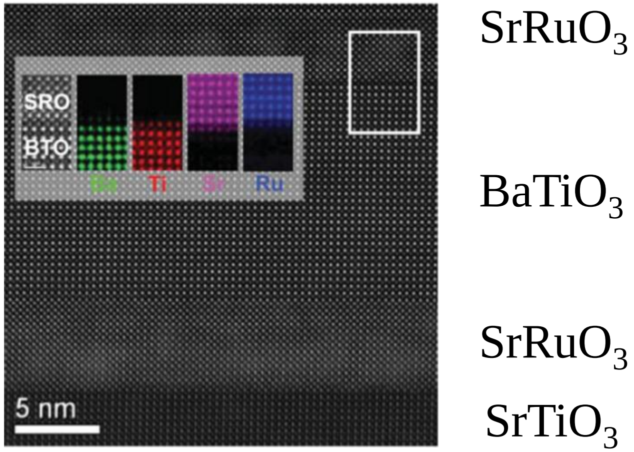


M. F. Sarott, E. Gradauskaite, J. Nordlander,
N. Strkalj, M. Trassin. J. Phys.: Condens. Matter. **33** (2021) 293001

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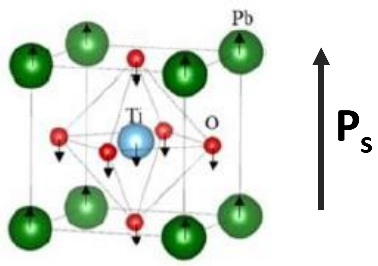
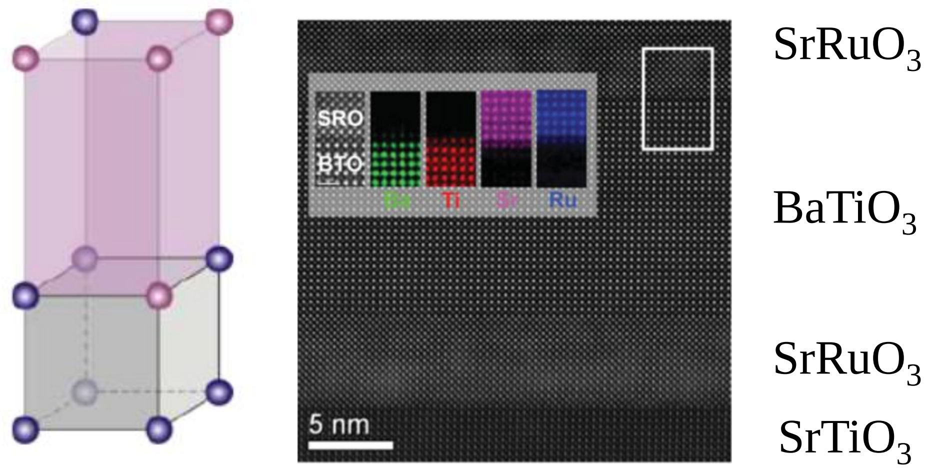
**Perovskite**

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**Complex oxides substrates:**
- Expensive
- Difficult to process
- Limited size
- Limited use in industry

# Difficulty to integrate oxides on silicon and glass:

- High reactivity of Si with $O_2$: propensity to form amorphous $SiO_2$ at the interface
- Structural and chemical dissimilarities
- Differences in thermal expansion coefficients
- Reaction of oxides with Si

→ - Very low crystalline quality
- Degradation of the properties

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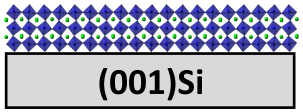
→ - Very low crystalline quality
- Degradation of the properties

Breakthrough 1998: McKee *et al*. PRL 81 : first demonstration that $SrTiO_3$ can be grown directly on Si with an atomically sharp interface using MBE

Heteroepitaxy of a thin template layer
of $SrTiO_3$ on Si




$SrTiO_3$
$Y_2O_3:ZrO_2$ (YSZ)
$CeO_2$/YSZ

} template layer by Pulsed Layer Deposition (PLD)

Fork *et al*. APL 57 (1990) 1137
Perna *et al*. *J. Phys. Cond. Matter*. 21 (2009) 30
Diaz-Fernandez *et al*. *Appl. Surf. Sci*. 455 (2018) 227

$ZrO_2$ template layer by Atomic Layer Deposition (ALD)

Dogan *et al*. J. Phys. Chem. C 123 (2019) 15053

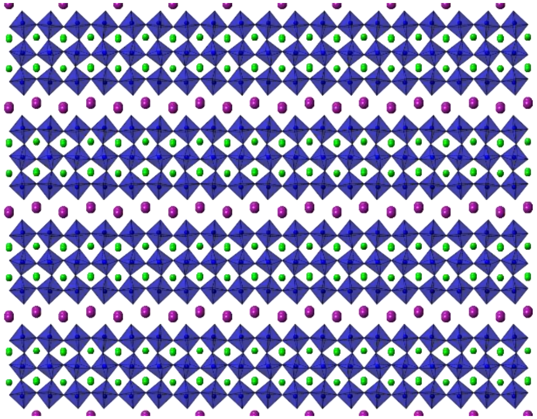
**Limitations:** Complex technics

**Advantages:** High crystalline quality of the template layer

# Oxide metals nanosheets: template layers for oxides

**Pioneer work of Sasaki's group (NIMS, Japan), 2007**

**Layered metal oxide**



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**Exfoliation in solution**

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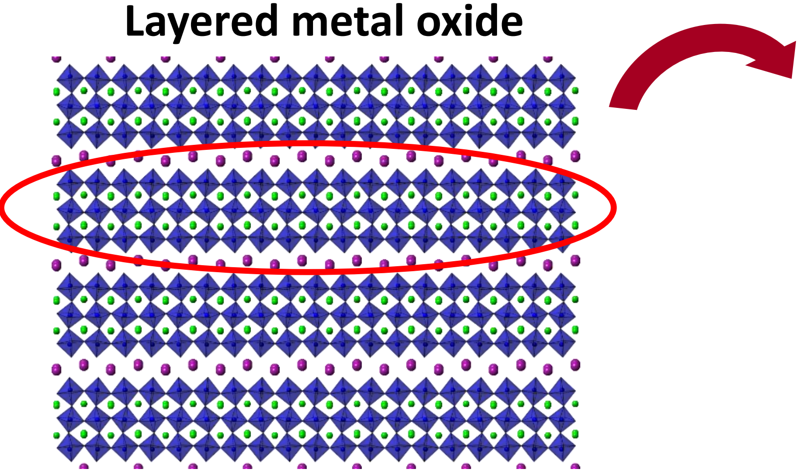
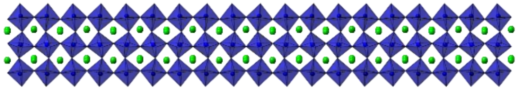


**Oxide metals nanosheets**



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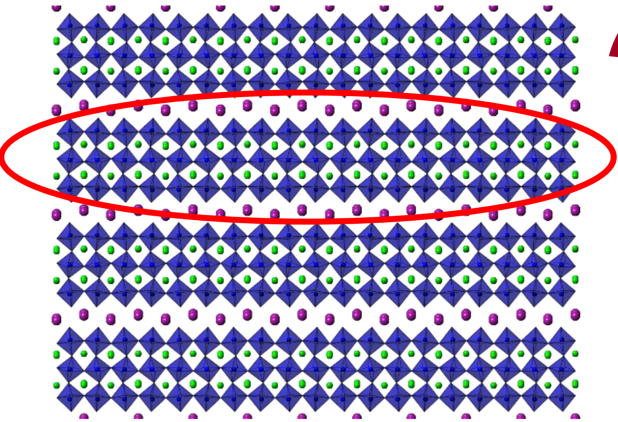

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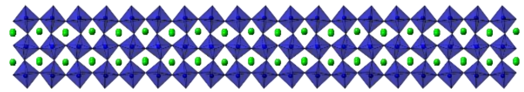

**Transfer**

**Chemical solution route**
**Room temperature**
**Atmospheric pressure**

**Van der Waals bonding**

| |
|---|
| $SiO_2$/Silicon<br>Glass<br>Other substrates |

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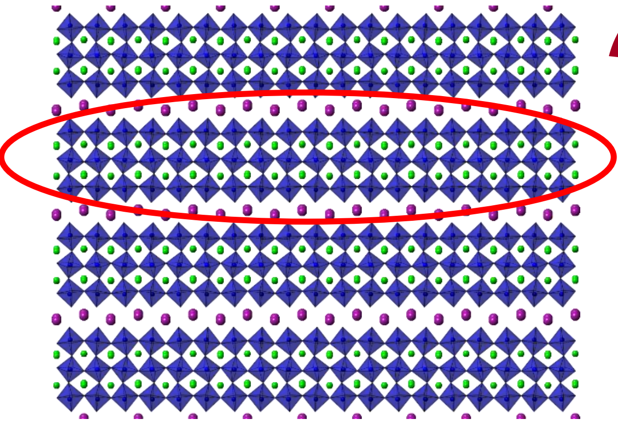

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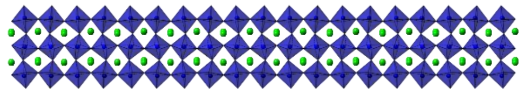


**Transfer**

**Chemical solution route**
**Room temperature**
**Atmospheric pressure**

**Van der Waals bonding**

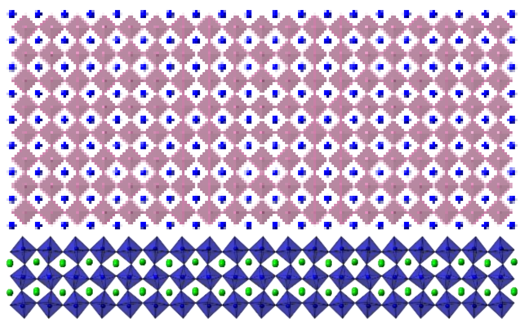
$SiO_2$/Silicon
Glass
Other substrates

**Growth**

**PLD, PVD, CSD, ALD**

**(Oxide) thin film**

**Oxide nanosheet**

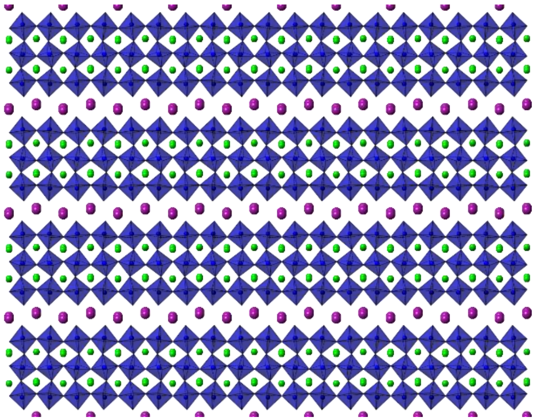


$SiO_2$/Silicon
Glass
Other substrates

# Oxide metals nanosheets: template layers for oxides

## Synthesis

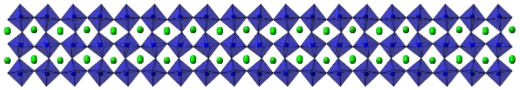
Layered metal oxide



**Synthesis: 2 weeks**
**Storage: years**

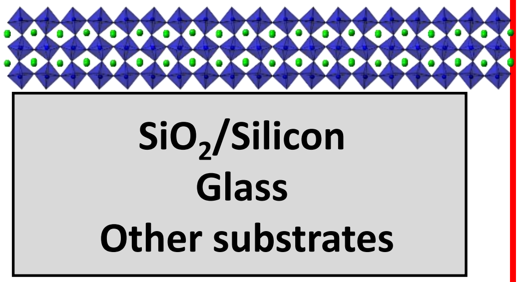
## Exfoliation in solution

Oxide metals nanosheets



**Synthesis: 2 weeks**
**Storage: 6 months**

## Transfer



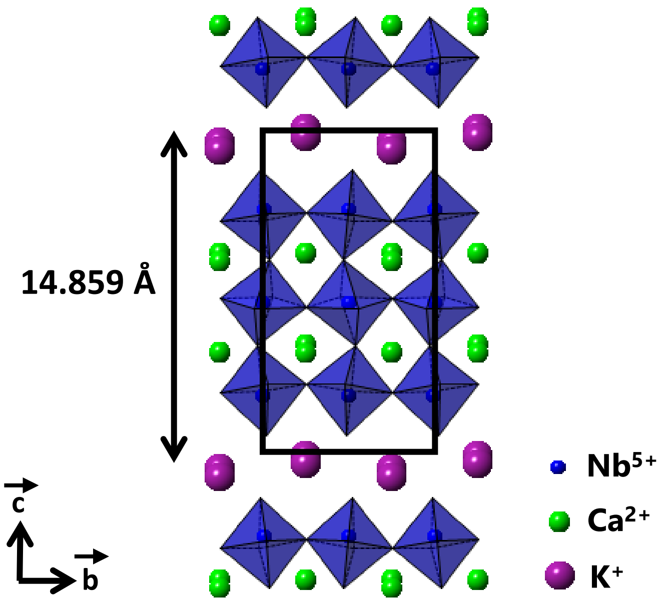

**Process: 3 hours**
**Storage: > 1 year**

# $[Ca_2Nb_3O_{10}]^-$: nanosheets for the growth of (001) perovskite

## Layered perovskite Dion-Jacobson phase: $AA'_{k-1}B_kO_{3k+1}$

**A: alkaline metal, A': alkaline-earth metal, B: transition metal**

**$KCa_2Nb_3O_{10}$ (KCN)**




***P*2$_1$*/m***

**$a$ = 7.741 Å, $b$ = 7.707 Å, $c$ = 14.859 Å, $\beta$ = 97.51°**

*(larger tetragonal cell description: a = 7.727 Å, b = 29.466 Å)*

M. Dion, M. Ganne, M. Tournoux. *Mater. Res. Bull*. 16 (1981) 1429
T. Tokumitsu, K. Toda, T. Aoyagi, D. Sakuraba, K. Uematsu, M. Sato. *J. Ceram. Soc. Jpn*. 114 (2006) 795

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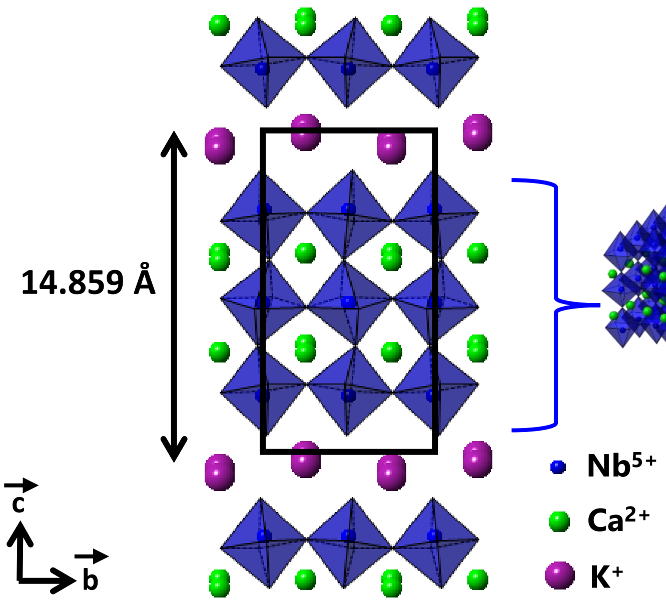
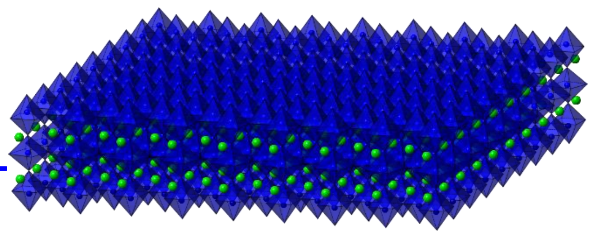



**After exfoliation:**

**Perovskite slab**



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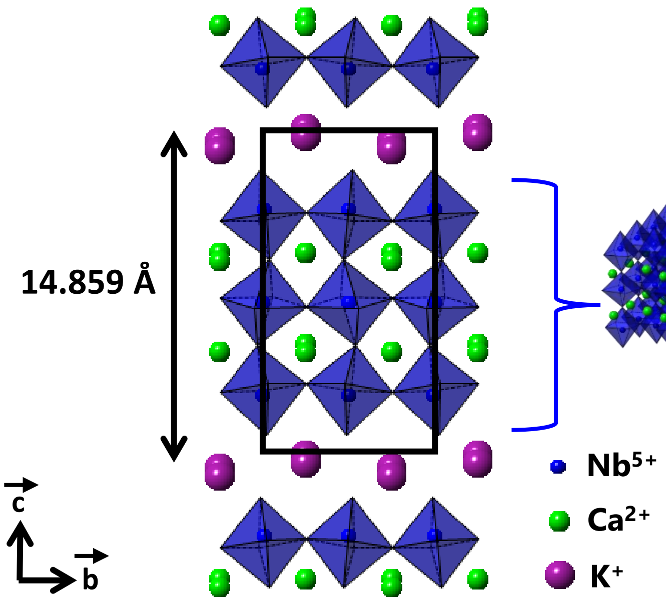


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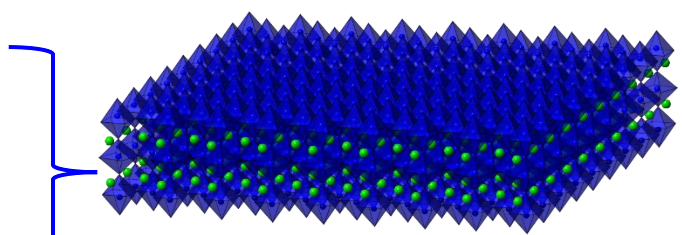
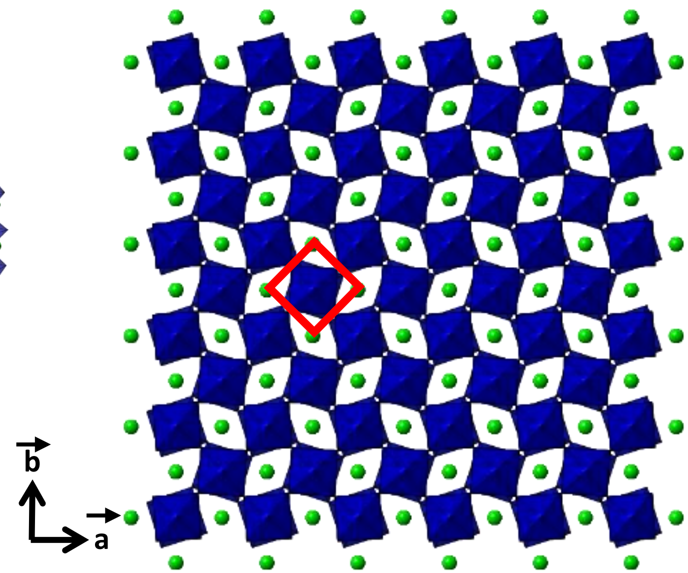


**In plane view of $[Ca_2Nb_3O_{10}]^-$**

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**Square lattice:**

**$a_{NS}$ ~ 3.85 Å**


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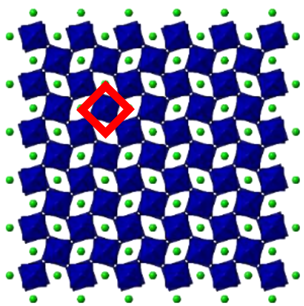
T. Tokumitsu, K. Toda, T. Aoyagi, D. Sakuraba, K. Uematsu, M. Sato. *J. Ceram. Soc. Jpn*. 114 (2006) 795

# Nanosheets for preferential orientation of oxides on any substrate

**PLD, Sputtering, Sol-gel**

| Nanosheets (NS) | 2D lattice | Grown films on NS | Substrates |
|---|---|---|---|
| $[Ca_2Nb_3O_{10}]^-$ | Square<br>$a_{NS}$ = 3.85 Å x 3.85 Å<br> | (001)$SrTiO_3$<br>(001)$(Ba,Sr)TiO_3$ | Glass |
| | | (001)$LaMnO_3$/STO SLs | Si |
| | | (001)LAO/STO SLs | Si |
| | | (001)$LaNiO_3$ | Si |
| | | (001)$BaTiO_3$ | Si |
| | | (001)$(K,Na)NbO_3$ | Pt/Ti/$SiO_2$/Si |
| | | (001)$BiFeO_3$ | Pt/Si, Pt/$TiO_2$/Si, 316LSS |
| | | (001)$Pb(Zr,Ti)O_3$ | Si, Pt/$TiO_2$/Si, glass, 316LSS |
| | | (001)$SrRuO_3$ | Si, Glass |
| | | (001)$(Ca,Sr)Bi_4Ti_4O_{15}$ | Pt/$TiO_2$/Si |
| | | (110)$(Sr,Eu)_2(Sn,Ti)O_4$ | Glass |
| | | (001)$TiO_2$ | Glass |

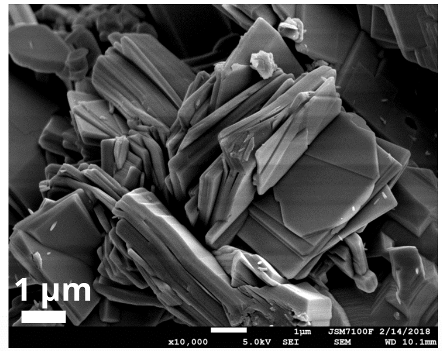
**Refs: Sasaki's articles, Ten Elshof's articles, …**

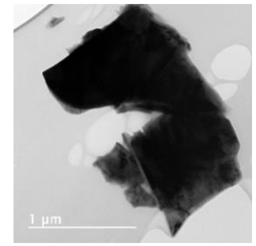
# Synthesis of $KCa_2Nb_3O_{10}$

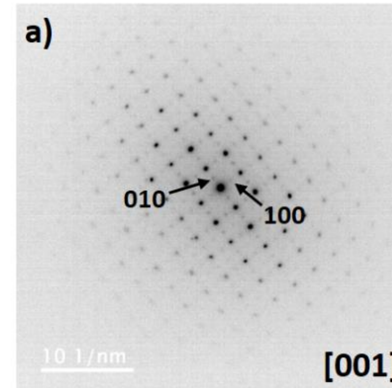
F. Baudouin
Institut des Sciences Chimiques de Rennes UMR CNRS 6226

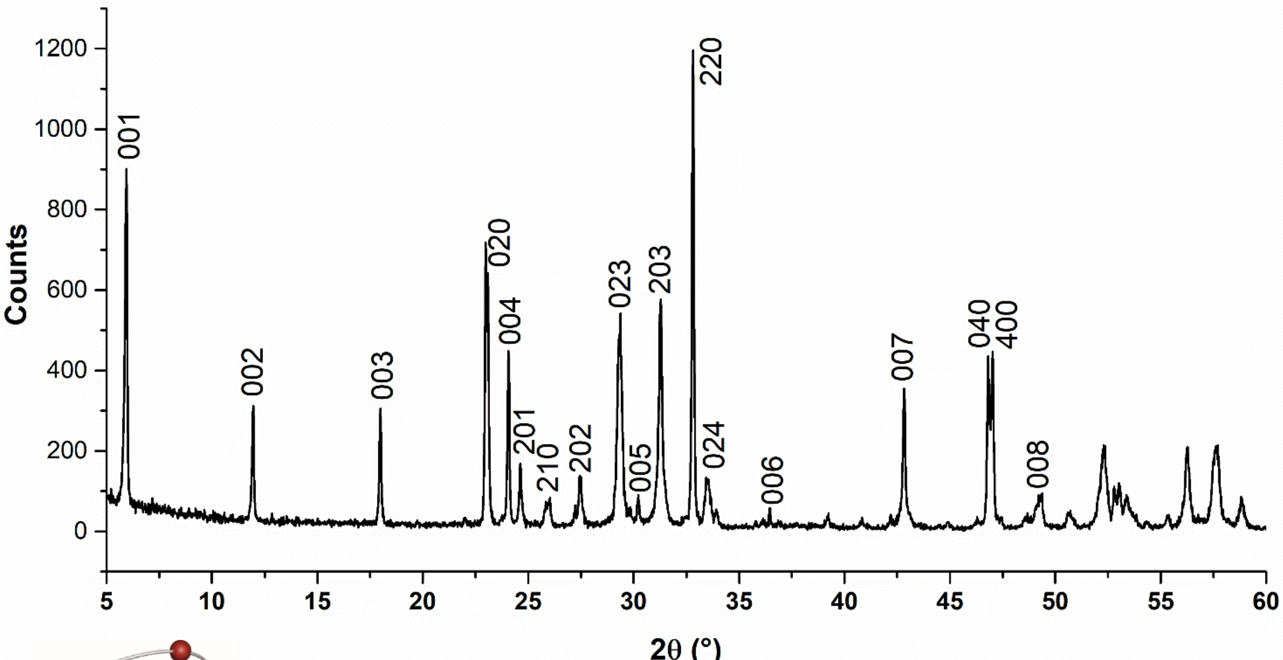
## Solid state reaction:

$$1/2\ K_2CO_3\ (+\ \text{excess}) + 2\ CaCO_3 + 3/2\ Nb_2O_5 \xrightarrow{1200°C} KCa_2Nb_3O_{10} + 5/2\ CO_2$$

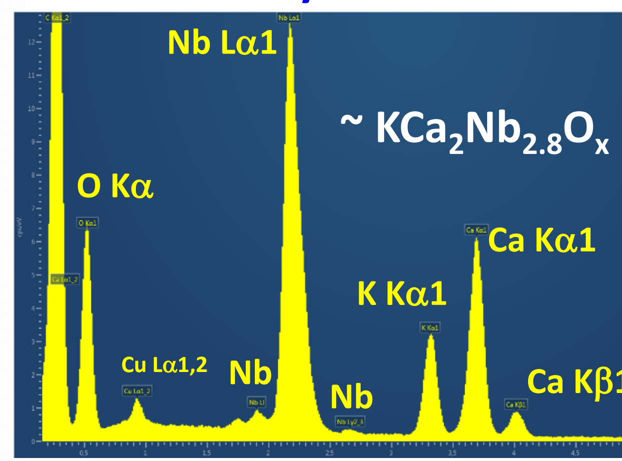


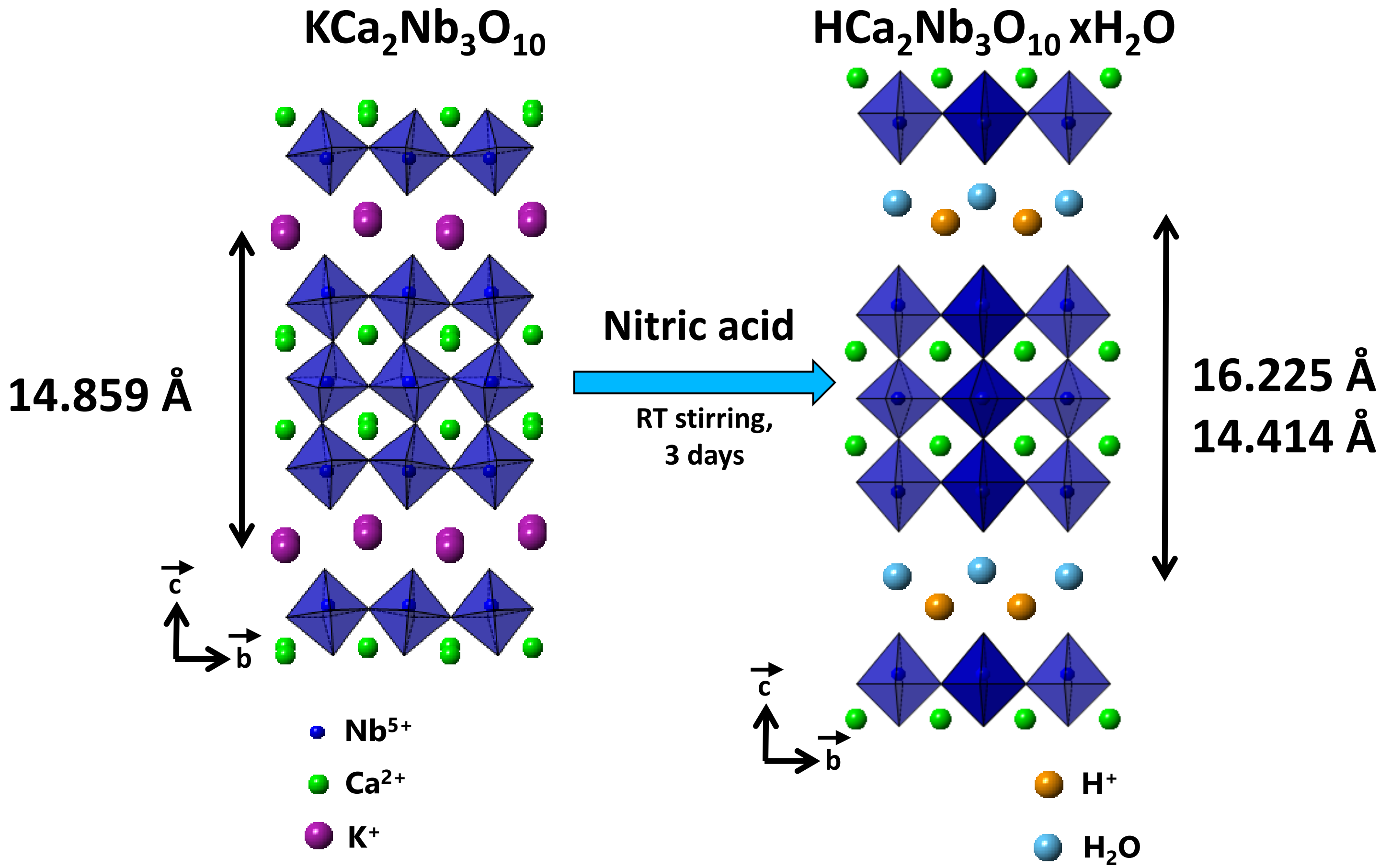




## EDXS analysis



# Protonation: ion exchange $K^+ \rightarrow H^+$




Moisture ↻ $HCa_2Nb_3O_{10}\ 1.5H_2O$ / $HCa_2Nb_3O_{10}\ 0.5H_2O$ ↻ 80°C 2 h

*Tetragonal*, $a$ = 3.854 Å, $c$ = 16.225 Å

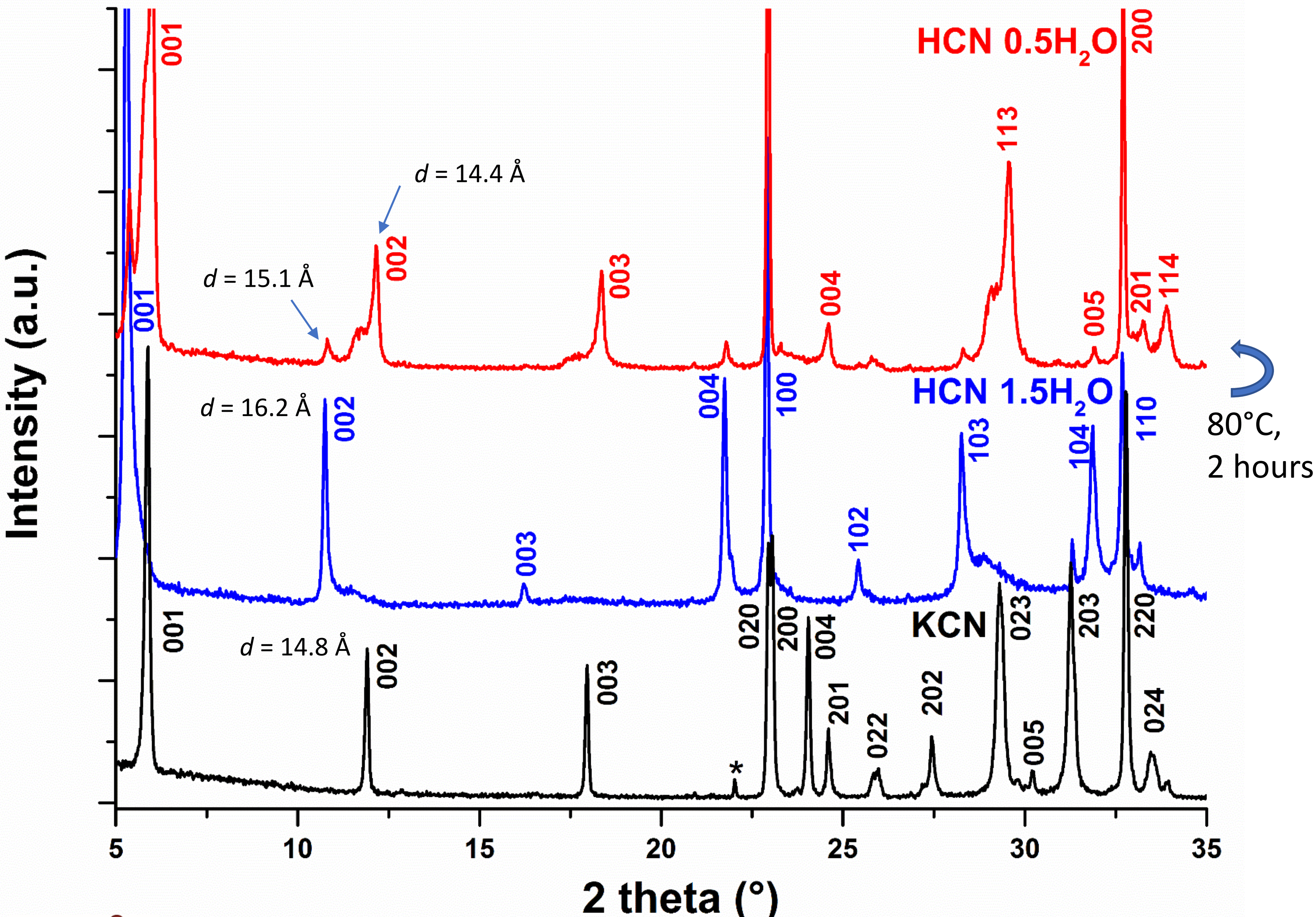
*P4/mbm*, $a$ = 5.452 Å, $c$ = 14.414 Å


A.J. Jacobson, J.T. Lewandowski, J.W. Johnson. *J. Common Met*. 116 (1986) 137

Y. Chen, X. Zhao, H. Ma, S. Ma, G. Huang, Y. Makita, X. Bai, X. Yang. *J. Solid State Chem*. 181 (2008) 1684

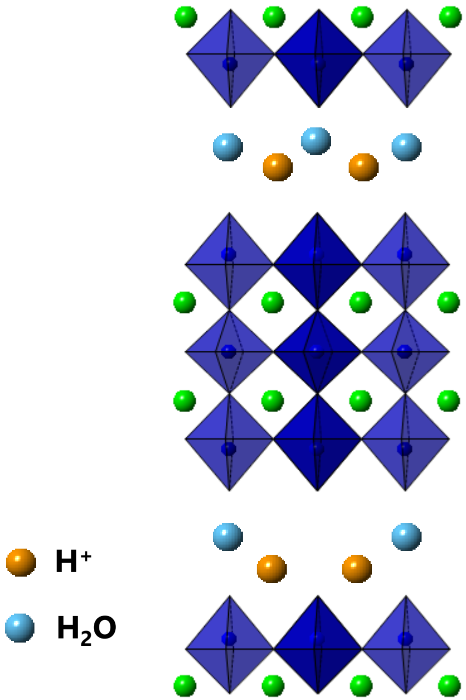
L.V. Yafarova, O.I. Silyukov, T.D. Myshkovskaya, I.A. Minich, I.A. Zvereva. *J. Therm. Analysis. Calorim*. (2020)

# X-ray diffraction



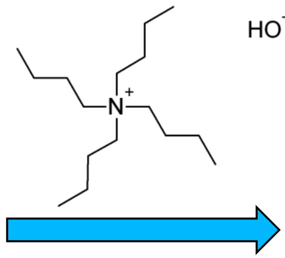
# Exfoliation

**HCN 1.5$H_2O$**




**TBAOH + $H_2O$**

**$(C_4H_9)_4NOH$**

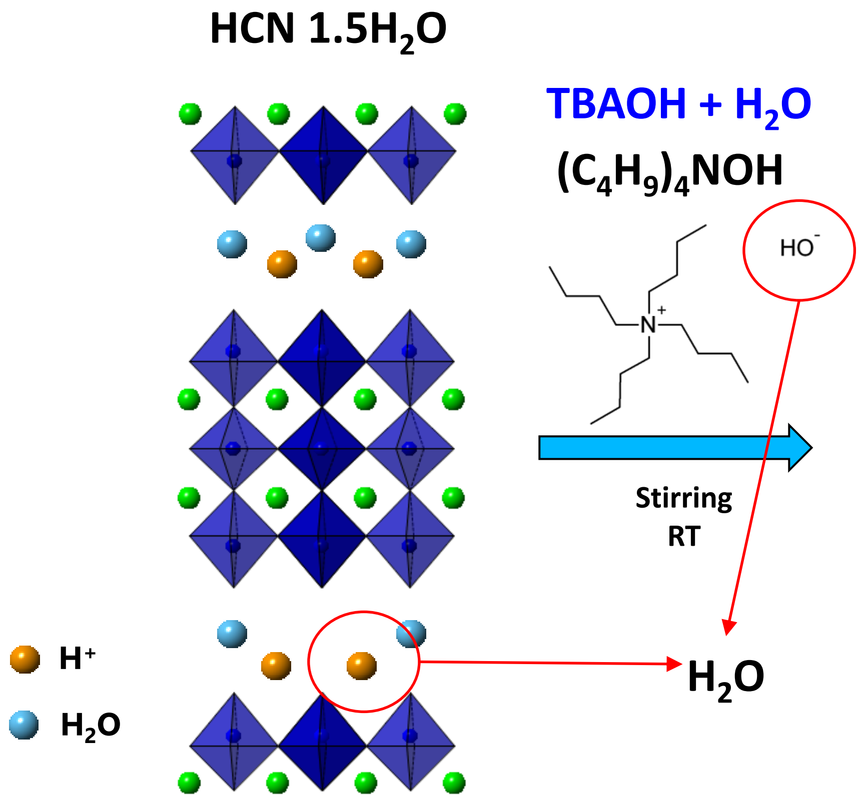



**Stirring**
**RT**

**Tetra(n-butyl)ammonium hydroxide (TBAOH)**


**R.E. Schaak, T. Mallouk. *Chem. Mater*. 12 (2000) 2513**
**H. Yuan, D. Dubbink, R. Besselink, J.E. Elshof. *Angew. Chemie. Int. Ed*. 54 (2015) 9239**
**J.E. Elshof. H. Yuan, P Gonzalez Rodriguez. *Mater. Views*. 6 (2016) 1600355**

# Exfoliation




Tetra(n-butyl)ammonium hydroxide (TBAOH)

**- Acid-base reaction between $OH^-$ from TBAOH and $H^+$ from HCN**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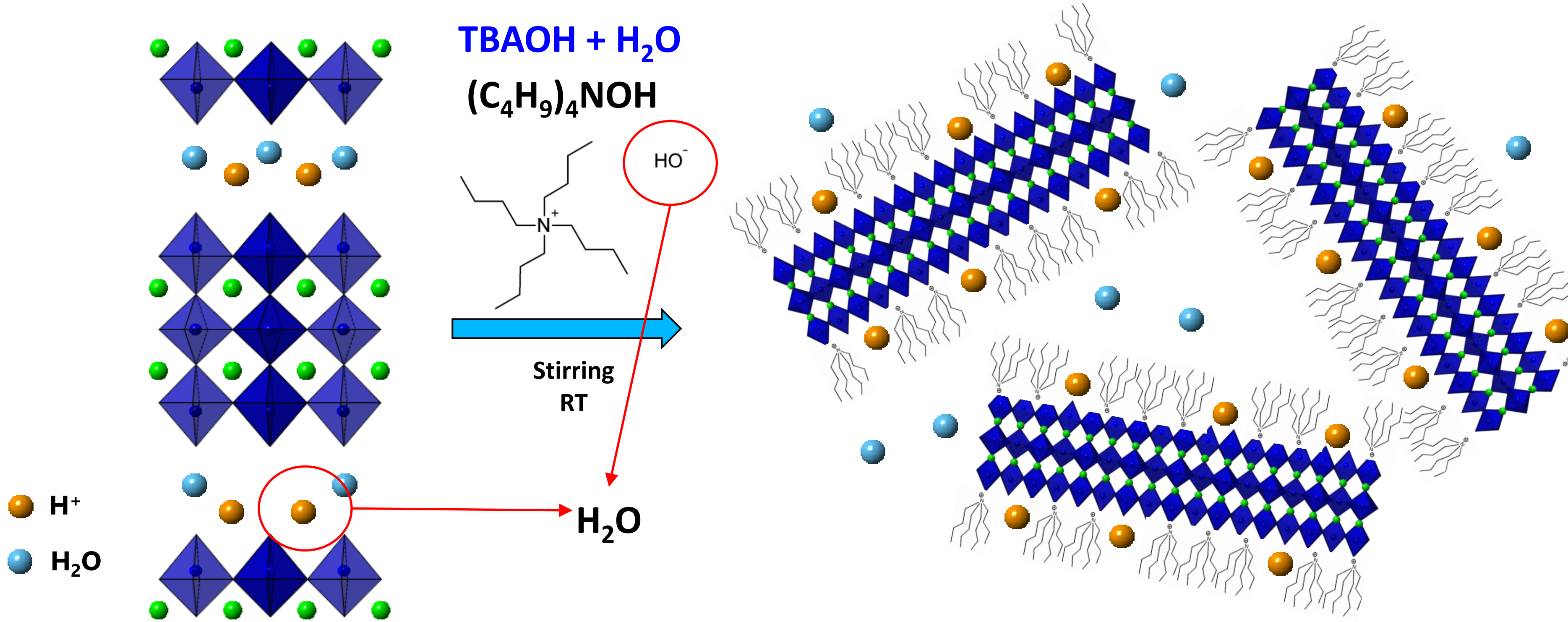
# Exfoliation

**HCN 1.5$H_2O$**

**$[H_{1-y}TBA_y]^+[Ca_2Nb_3O_{10}]^-$ nanosheets colloïdal suspension**




**Tetra(n-butyl)ammonium hydroxide (TBAOH)**

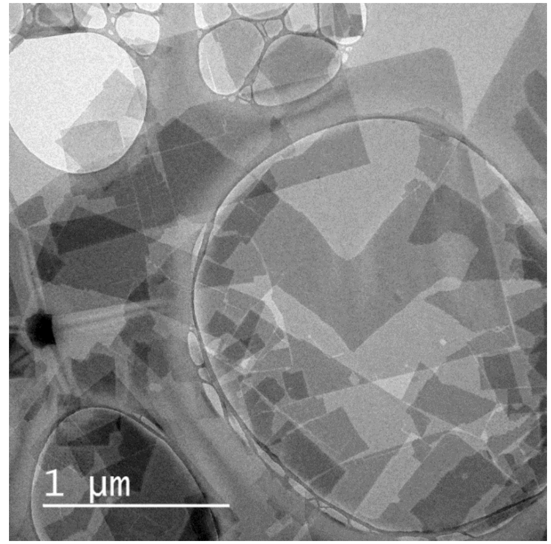
**Nanosheets in solution:**
**$[H_{1-y}TBA_y]^+[Ca_2Nb_3O_{10}]^-$ + $H_2O$**

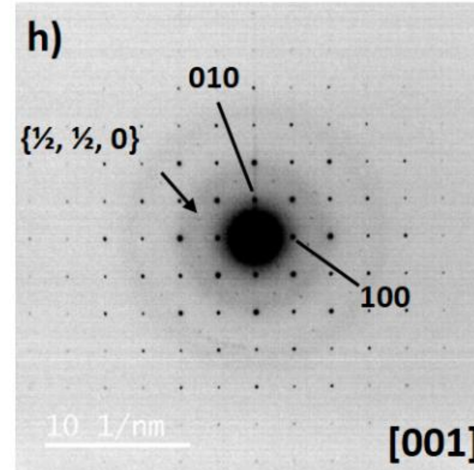
- **Acid-base reaction between $OH^-$ from TBAOH and $H^+$ from HCN**
- **TBA keep nanosheets in a well-dispersed state in water**

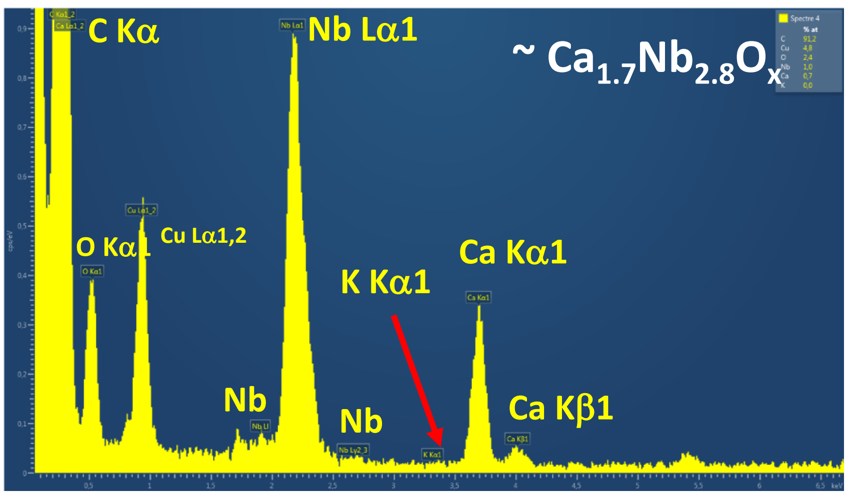

R.E. Schaak, T. Mallouk. *Chem. Mater*. 12 (2000) 2513
H. Yuan, D. Dubbink, R. Besselink, J.E. Elshof. *Angew. Chemie. Int. Ed*. 54 (2015) 9239
J.E. Elshof. H. Yuan, P Gonzalez Rodriguez. *Mater. Views*. 6 (2016) 1600355

# $[Ca_2Nb_3O_{10}]^-$ nanosheets


**Nanosheet colloidal suspension: Tyndall effect**



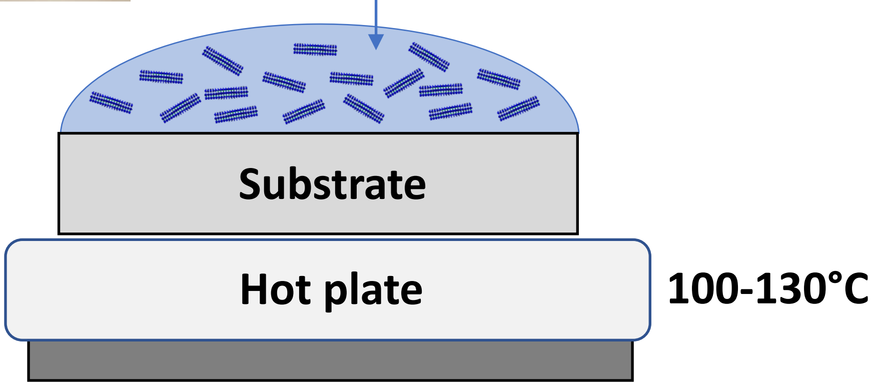

**Weak superlattice {½, ½, 0} reflections:**
**$\sqrt{2}a$ lattice constant ~ 5.46 Å**

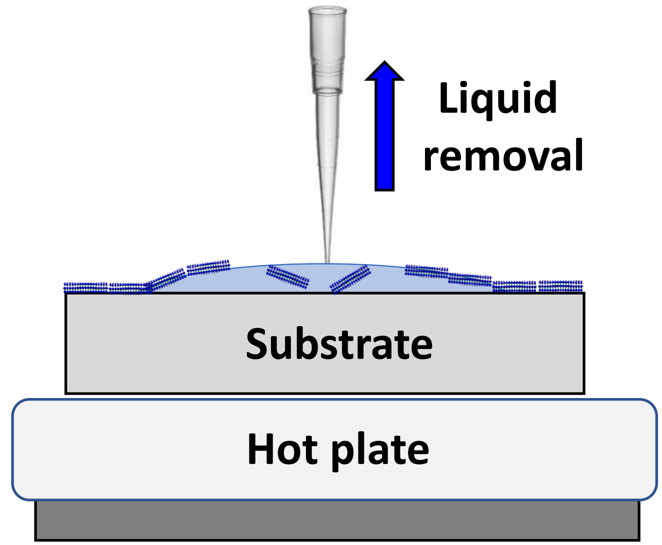
A. Maia, F. Cheviré, V. Demange, V. Bouquet, M. Pasturel, S. Députier, R. Lebullenger, M. Guilloux-Viry, F. Tessier. *Solid State Sci*. 54 (2016) 17-21
F. Baudouin, V. Demange, S. Ollivier, L. Rault, A. S. Brito, A. S. Maia, F. Gouttefangeas, V. Bouquet, S. Députier, B. Bérini, A. Fouchet, M. Guilloux-Viry. *Thin Solid Films* 693 (2020) 137682

# Nanosheets seed layer deposition by drop-casting method

**Y. Shi, M. Osada, Y. Ebina, T. Sasaki. *ACS Nano* 14 (2020) 15216**

**Nanosheets solution**
**+ ethanol**
**+ water**

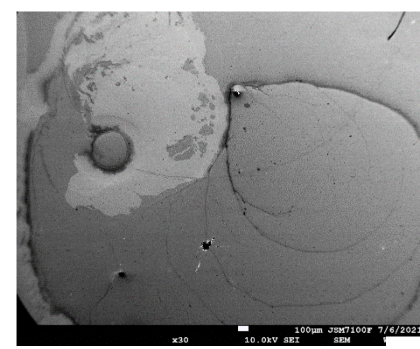



- Easy
- Fast (dozens samples/day)
- No waste of material
- Large substrates (several $cm^2$)

**Limitations:**

« Coffee-ring » marks
Operator dependent

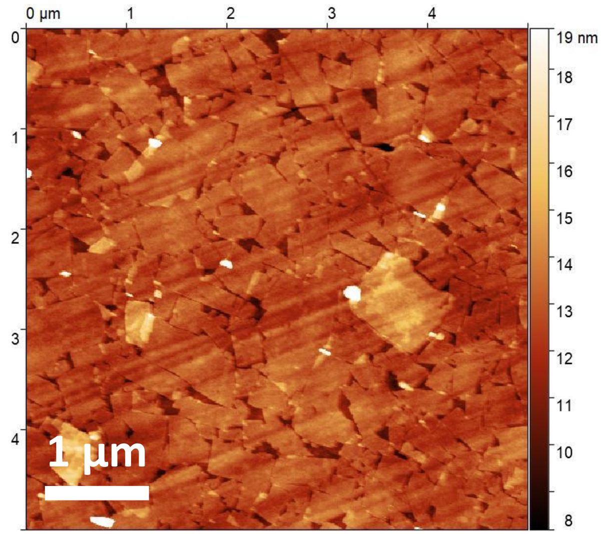


# After deposition: atomic force microscopy/SEM

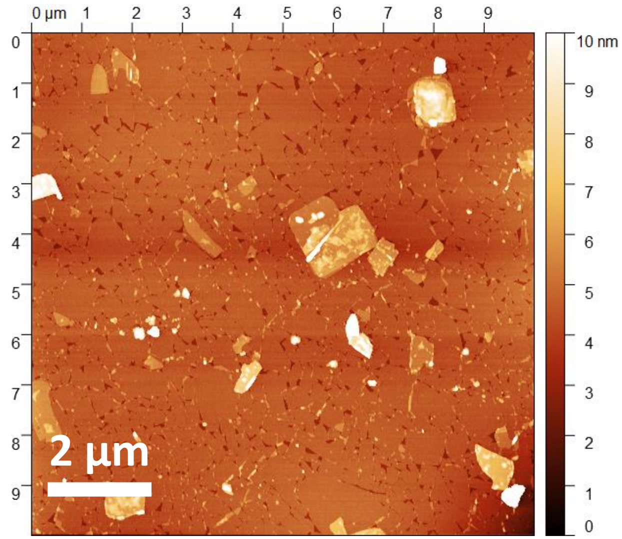
S. Ollivier

B. Bérini

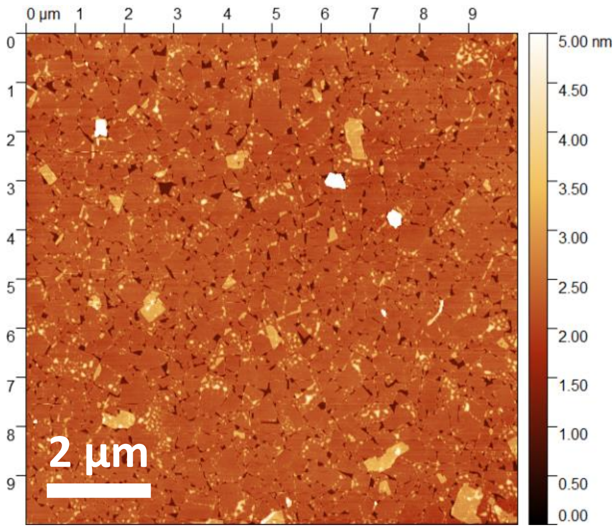
## On $SiO_2$



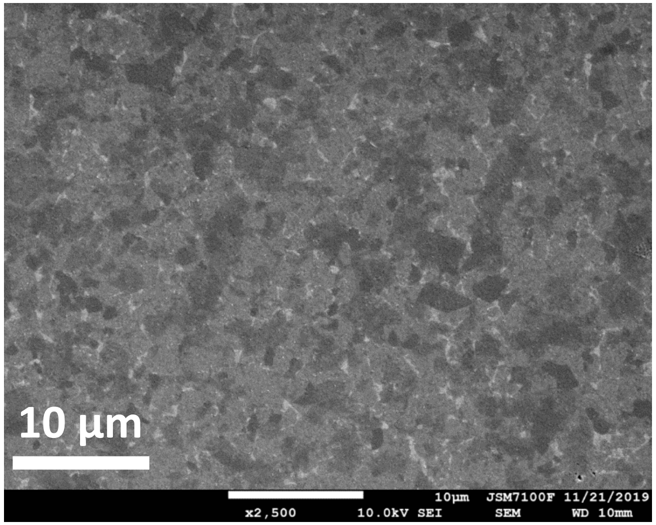

## On (100)Si




## On mica




## On Pt/Si

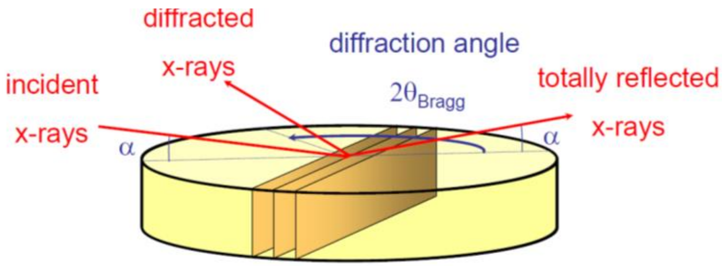


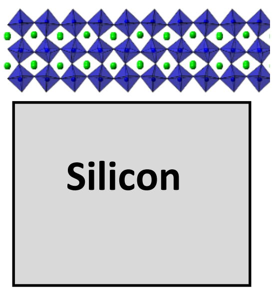

**Height: e = 1.5-1.9 ± 0.3 nm**

**Coverage: > 90 %**

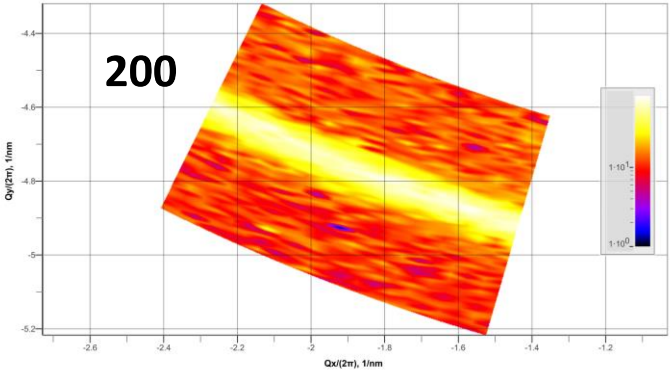
# After deposition: in-plane X-ray diffraction

Rigaku 5-circles

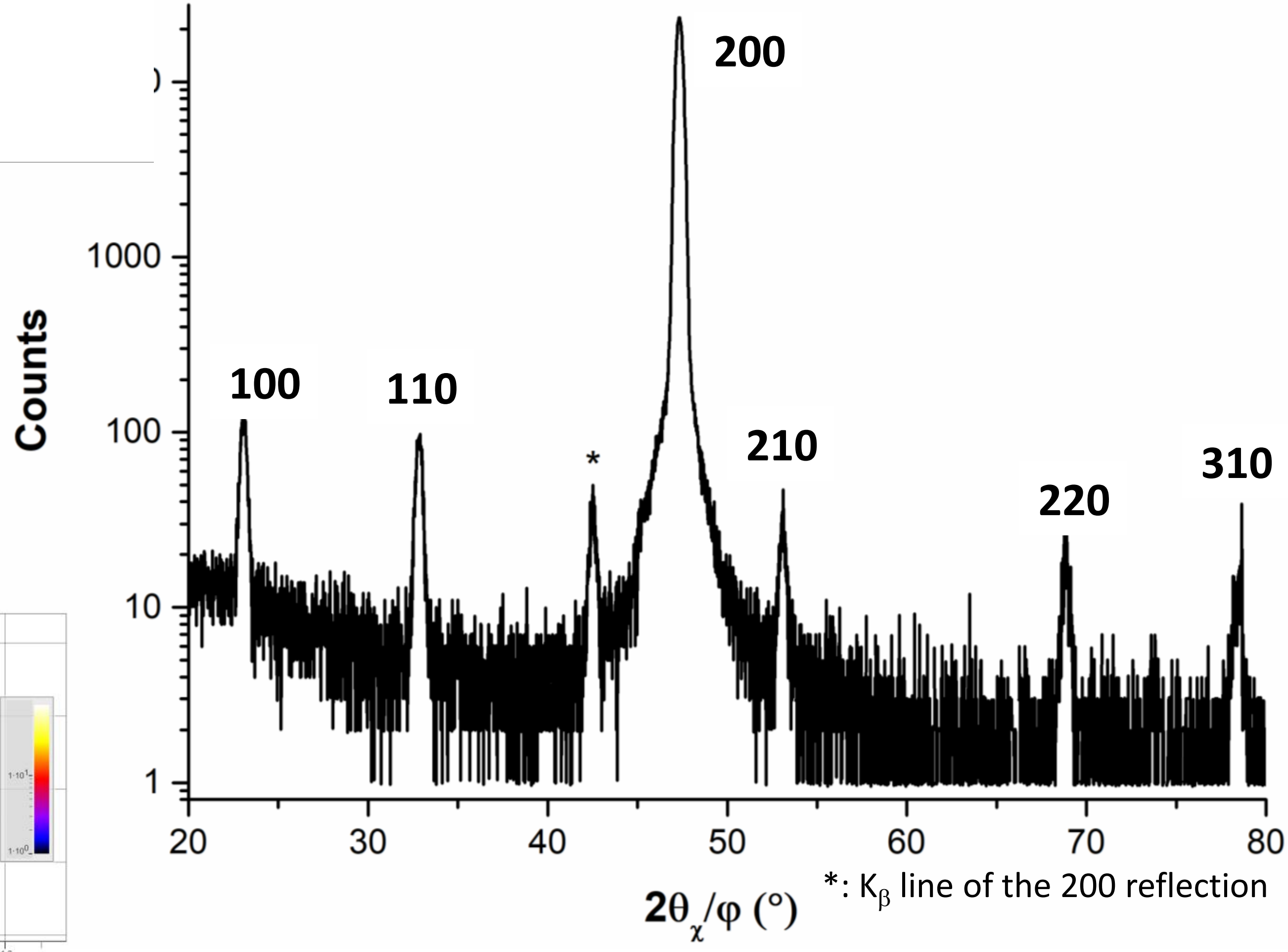



In-plane RSM




$[Ca_2Nb_3O_{10}]^-$ /Si



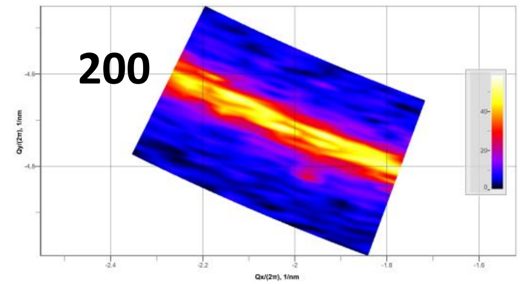

*: $K_\beta$ line of the 200 reflection

**200 reflection => *a* = 3.84 Å**

# Random in-plane distribution of nanosheets on the substrate

→ **Texturation of the film grown on nanosheets covered substrate**


**$La_{0.67}Sr_{0.33}MnO_3$ on $[Ca_2Nb_3O_{10}]^-$/glass**

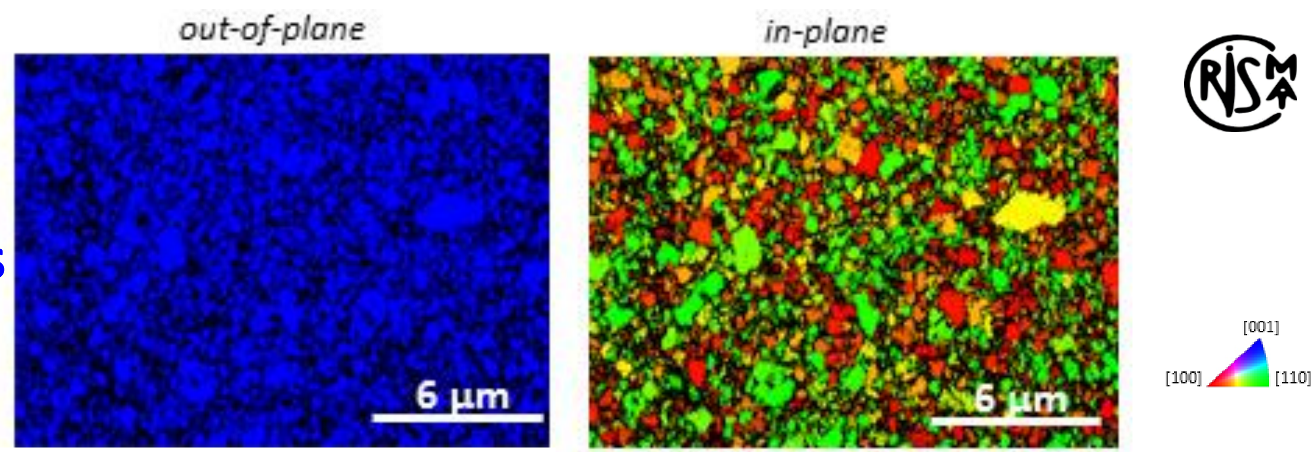



**In-plane RSM**

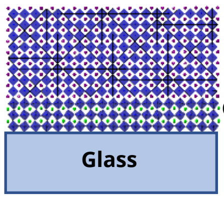
**EBSD**

M. Dallocchio

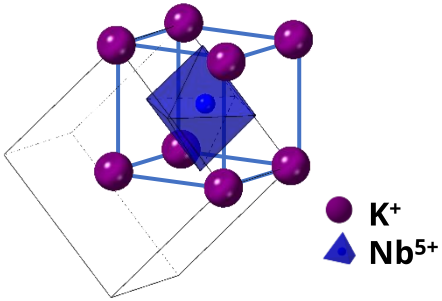
**$CaVO_3$ on $[Ca_2Nb_3O_{10}]^-$/glass**



# Growth of complex oxides: $KNbO_3$ on $[Ca_2Nb_3O_{10}]^-$/glass




**Ferroelectric $KNbO_3$ (KNO)**




***Amm2***

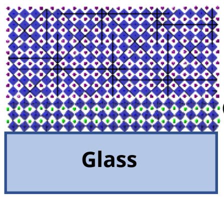
**$a$ = 3.9741(0) Å; $b$ = 5.6965(0) Å; $c$ = 5.726(1) Å**

**Pseudo-cubic cell:**

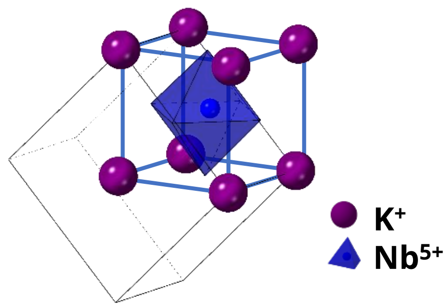
**$a_{pc}$ = 3.971 Å, $b_{pc}$ = 4.027 Å, $c_{pc}$ = 4.045 Å**

L. Katz and H.D. Megaw. *Acta Cryst*. 22 (1967) 639
S. Kawamura *et al*. *Jpn J. Appl. Phys*. 52 (2013) 09KF04

# Growth of complex oxides: $KNbO_3$ on $[Ca_2Nb_3O_{10}]^-$/glass




**Ferroelectric $KNbO_3$ (KNO)**

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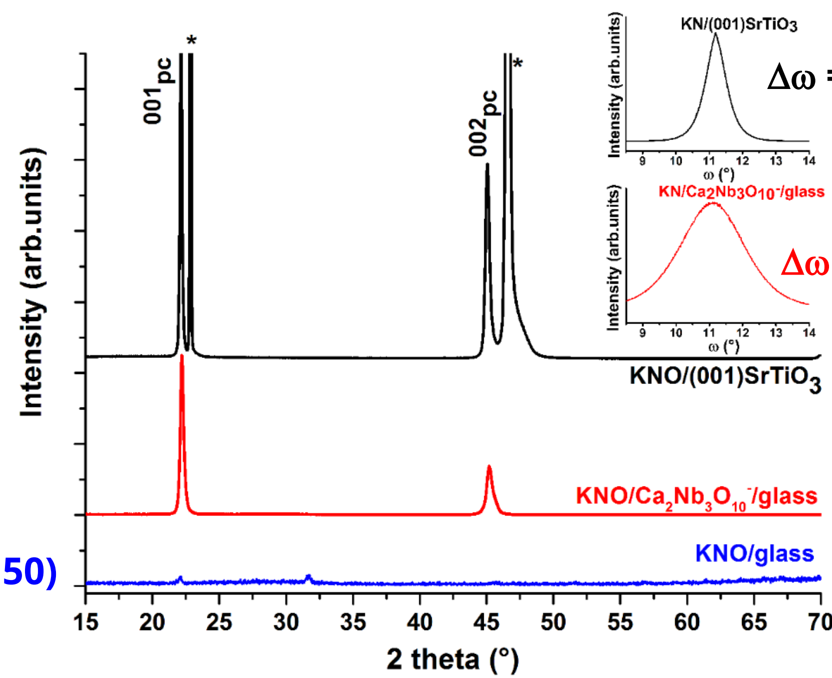
L. Katz and H.D. Megaw. *Acta Cryst*. 22 (1967) 639
S. Kawamura *et al*. *Jpn J. Appl. Phys*. 52 (2013) 09KF04

## Pulsed Laser Deposition: on $SrTiO_3$, on glass, on $[Ca_2Nb_3O_{10}]^-$/glass

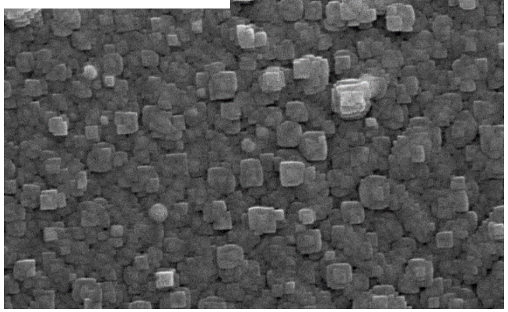
Thickness ~ 150 nm

*: $SrTiO_3$

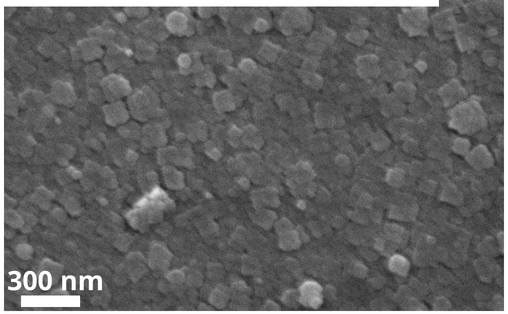
(Int. x 50)




On $SrTiO_3$



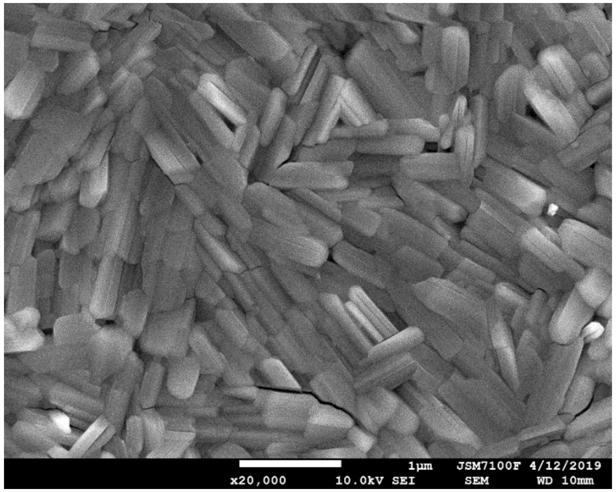
On $[Ca_2Nb_3O_{10}]^-$/glass




F. Baudouin, V. Demange, S. Ollivier, L. Rault, A.S. Brito, A.S. Maia, F. Gouttefangeas, V. Bouquet, S. Députier, B. Bérini, A. Fouchet, M. Guilloux-Viry. *Thin Solid Films* 693 (2020) 137682

# Growth of complex oxides: $KNbO_3$ on $[Ca_2Nb_3O_{10}]^-$/Si

**$KNbO_3$/Si**




**$K_6Nb_6Si_4O_{26}$**

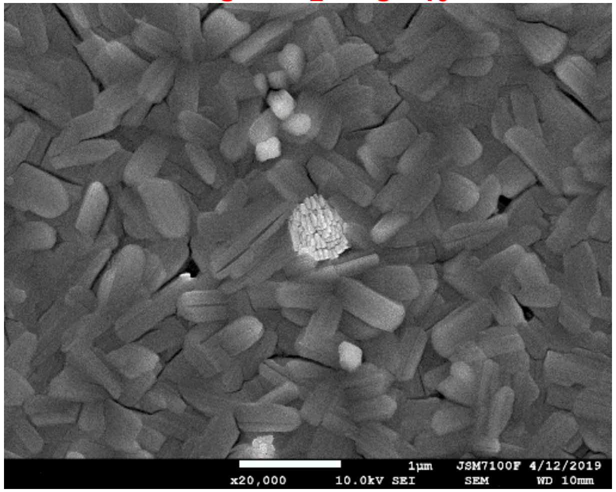
*P*-62*m*

$a = 9.032$ Å

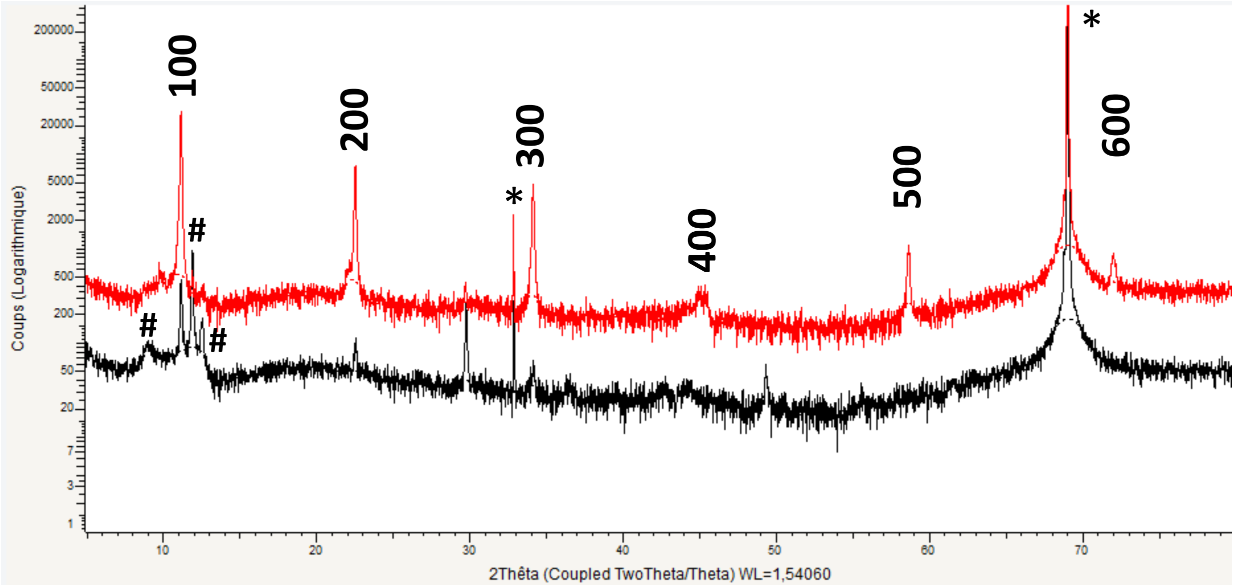
$c = 8.041$ Å

**J. Choisnet *et al.***
***Mater. Res. Bull.*** **11 (1976) 887**

**$KNbO_3/[Ca_2Nb_3O_{10}]^-$/Si**



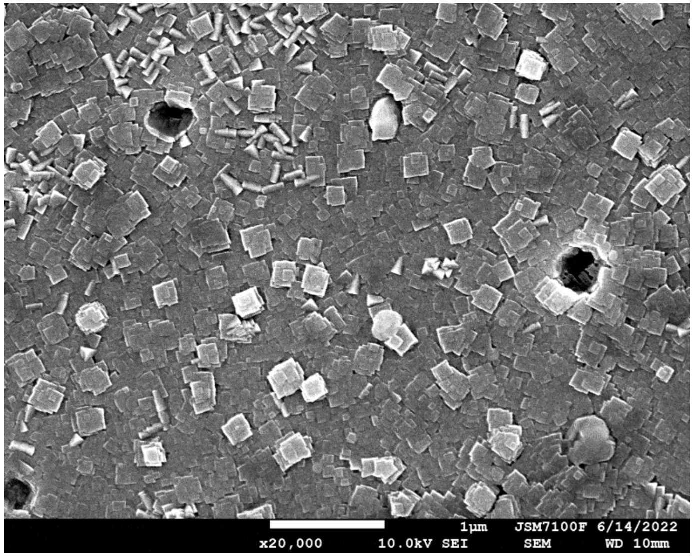

Thickness
~ 150 nm



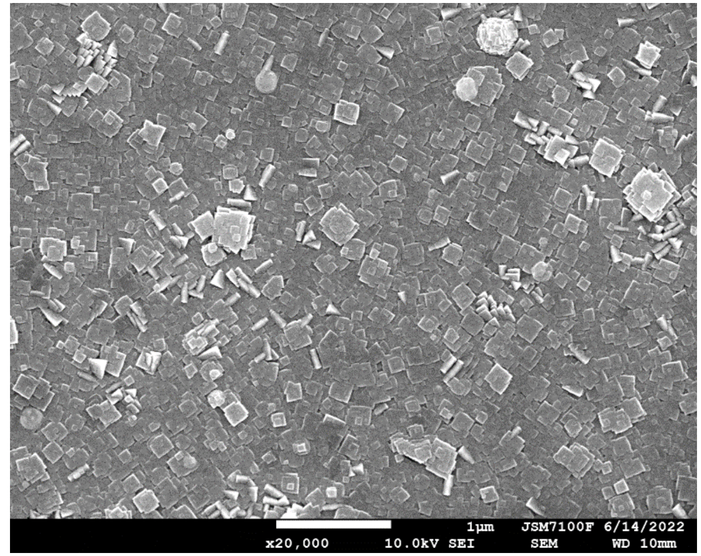

*** : Si**
**# : Unknown phase**

# Growth of complex oxides: $KNbO_3$ on $[Ca_2Nb_3O_{10}]^-$/Si

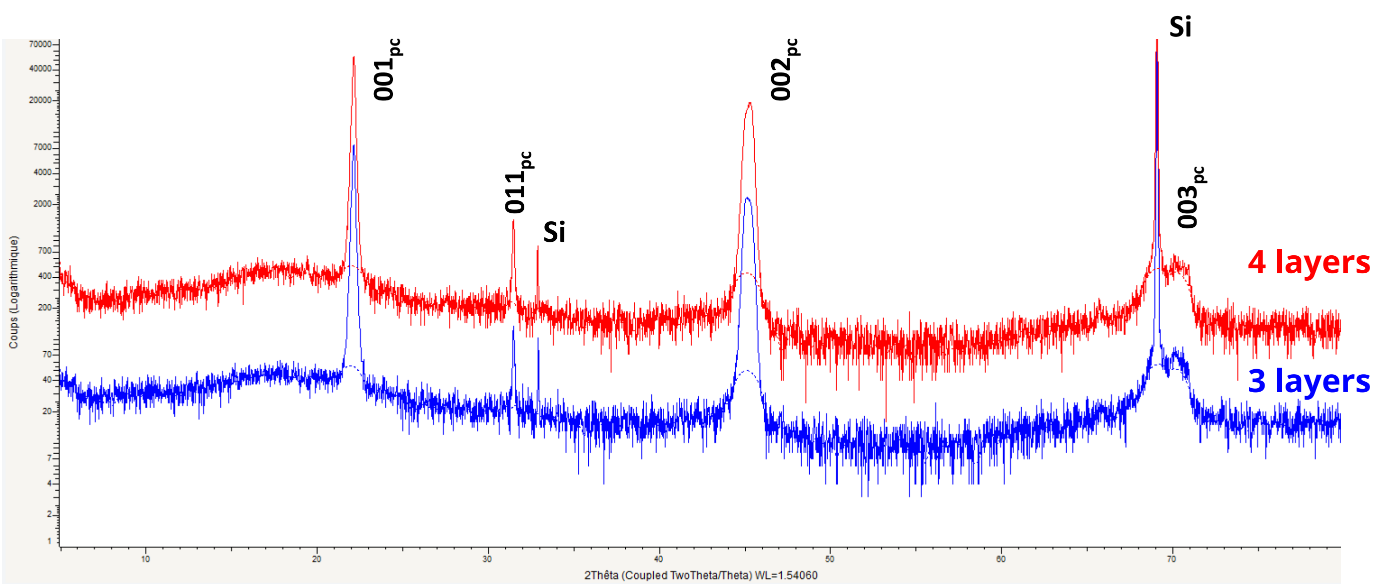
**$KNbO_3$/3 layers $[Ca_2Nb_3O_{10}]^-$/Si**



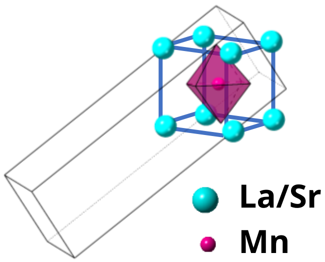

**$KNbO_3$/4 layers $[Ca_2Nb_3O_{10}]^-$/Si**




Thickness
~ 150 nm



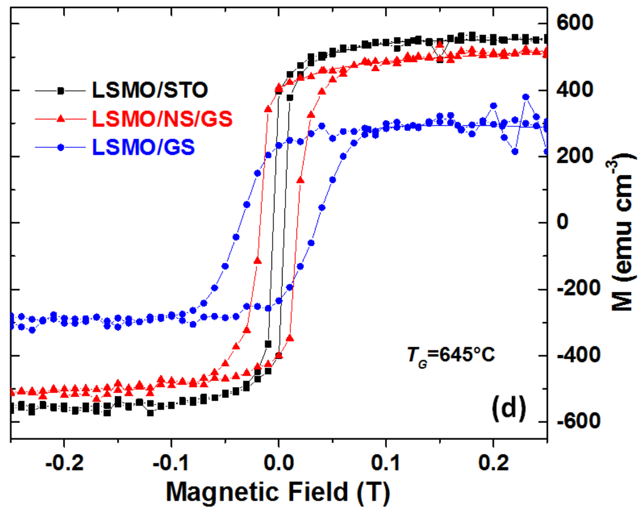
# Magnetic $La_{0.67}Sr_{0.33}MnO_3$ films on glass (PLD)



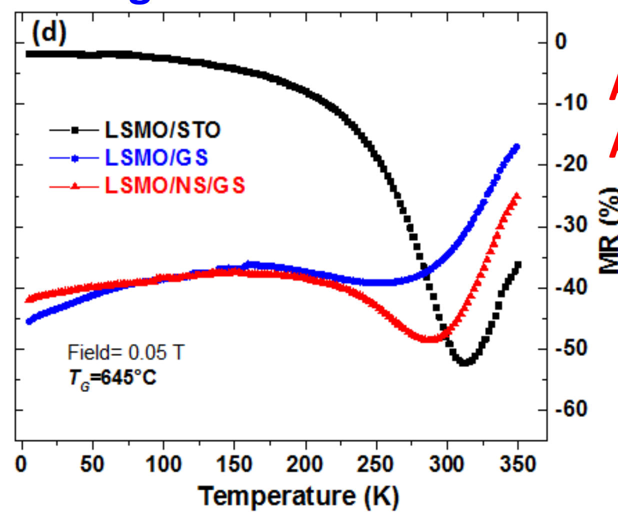

***R*$\bar{3}$*c***
**$a$ = 5.507 Å; $c$ = 13.367 Å**

**Pseudo-cubic cell:**
**$a_{pc}$ = 3.882 Å; $\alpha$ = 90.35°**

## Magnetization *vs* field



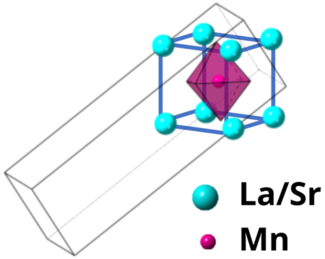

## Magnetoresistance *vs* T




A. Boileau
A. Fouchet

A. Boileau, M. Dallocchio, F. Baudouin, A. David, U. Lüders, B. Mercey, A. Pautrat, V. Demange, M. Guilloux-Viry, W. Prellier, A. Fouchet. *ACS Appl. Mater. Int*. 11 (2019) 37302

# Magnetic $La_{0.67}Sr_{0.33}MnO_3$ films on glass (PLD)




$R\bar{3}c$

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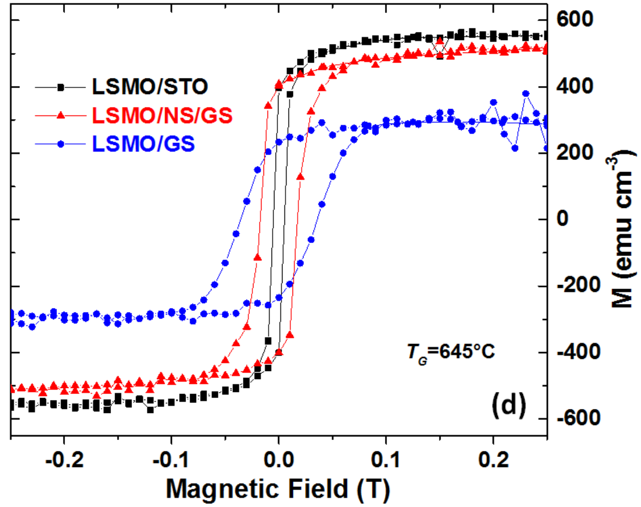
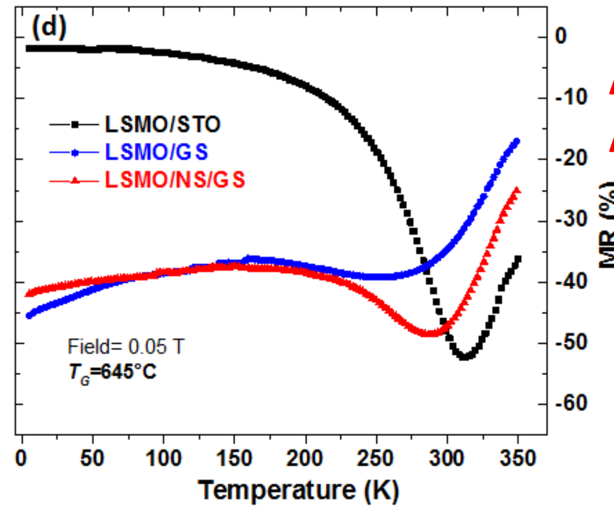
Pseudo-cubic cell:

$a_{pc}$ = 3.882 Å; $\alpha$ = 90.35°

## Magnetization *vs* field




## Magnetoresistance *vs* T

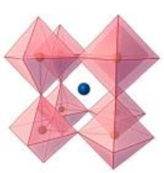



**A. Boileau**

**A. Fouchet**

A. Boileau, M. Dallocchio, F. Baudouin, A. David, U. Lüders, B. Mercey, A. Pautrat, V. Demange, M. Guilloux-Viry, W. Prellier, A. Fouchet. *ACS Appl. Mater. Int*. 11 (2019) 37302

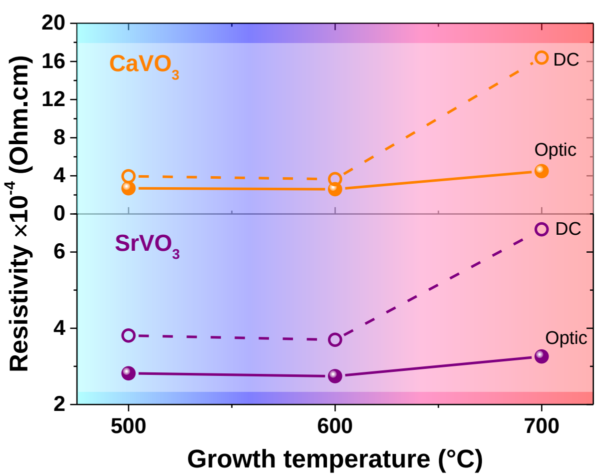
# Transparent conducting $SrVO_3$ and $CaVO_3$ films on glass (PLD)



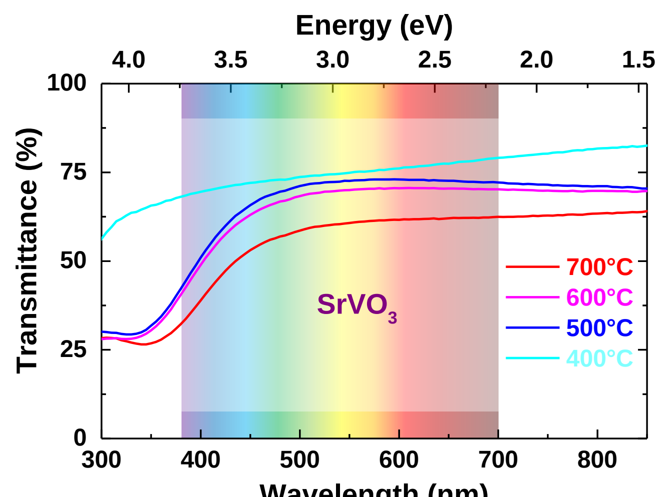
$Pm\bar{3}m$

$a$ = 3.84 Å

## Resistivity




## Transmittance




**A. Boileau**

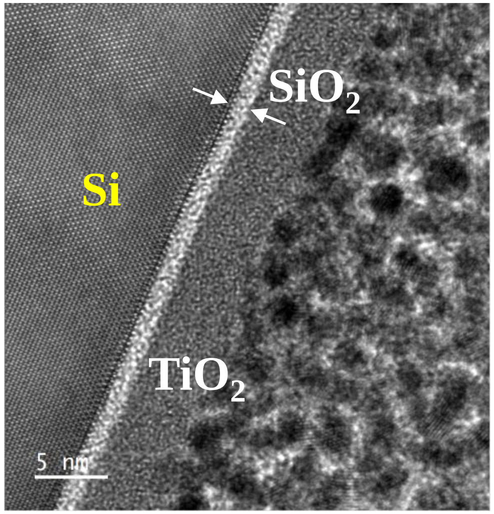
**A. Fouchet**

**Arnaud Fouchet's talk**

A. Boileau, S. Hurand, F. Baudouin, U. Lüders, M. Dallocchio, B. Bérini, A. Cheikh, A. David, F. Paumier, T. Girardeau, P. Marie, C. Labbé, J. Cardin, D. Aureau, M. Frégnaux, M. Guilloux-Viry, W. Prellier, Y. Dumont, V. Demange, A. Fouchet. *Adv. Func. Mater.* 32 (2022) 2108047

# $TiO_2$ thin films grown by atomic layer deposition (ALD)

## 5 nm $TiO_2$ on Si: amorphous




ALD

**A. Grishin**
**B. Bérini**

HR(S)TEM

**M. Vallet**

TEM

A. Grishin, B. Bérini, M. Vallet, S. Hurand, F. Maudet, C. Sartel, M. Frégnaux, S. Nowak, G. Amiri, S. Hassani, D. Aureau, V. Sallet, V. Demange, Y. Dumont. Appl. Surf. Science. 641 (2023) 158446

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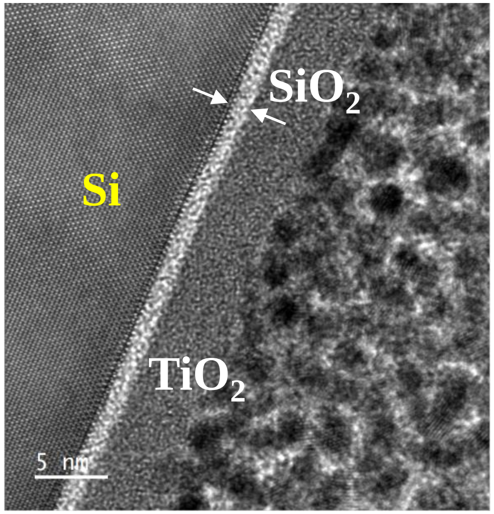
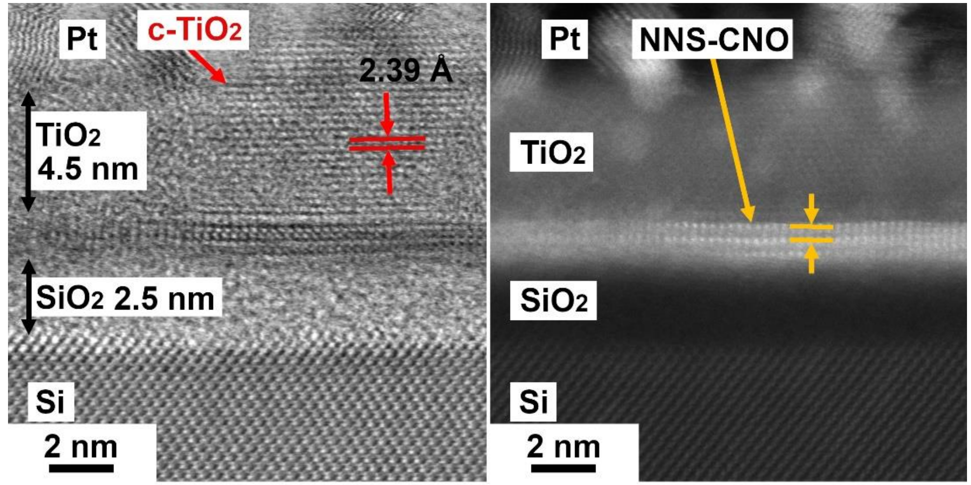



**5 nm $TiO_2$ on $[Ca_2Nb_3O_{10}]^-$/Si: crystalline film**




BF-STEM

HAADF-STEM

ALD

GEMaC

A. Grishin

B. Bérini

HR(S)TEM

Structures Properties Modeling of Solids

M. Vallet

TEM

Institut des Sciences Chimiques de Rennes UMR CNRS 6226


A. Grishin, B. Bérini, M. Vallet, S. Hurand, F. Maudet, C. Sartel, M. Frégnaux, S. Nowak, G. Amiri, S. Hassani, D. Aureau, V. Sallet, V. Demange, Y. Dumont. Appl. Surf. Science. 641 (2023) 158446

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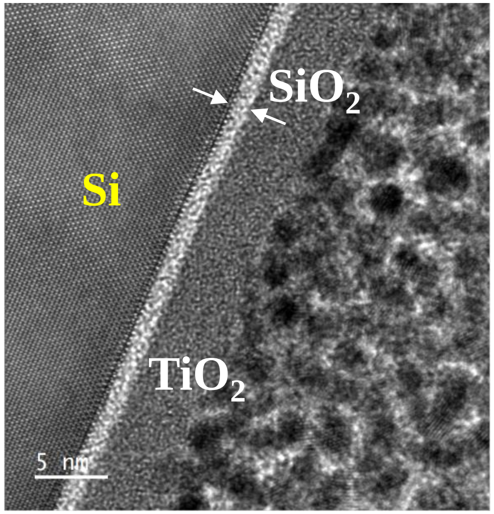
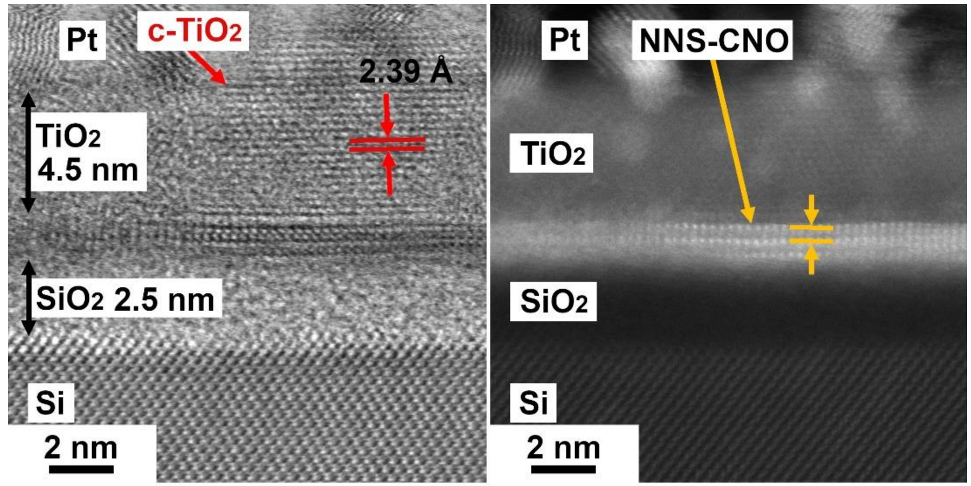



## 5 nm $TiO_2$ on $[Ca_2Nb_3O_{10}]^-$/Si: crystalline film




BF-STEM HAADF-STEM

ALD

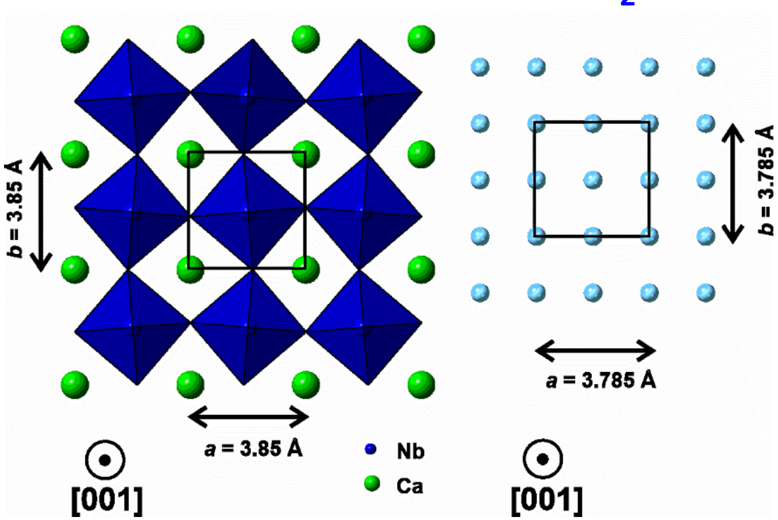
A. Grishin

B. Bérini

HR(S)TEM

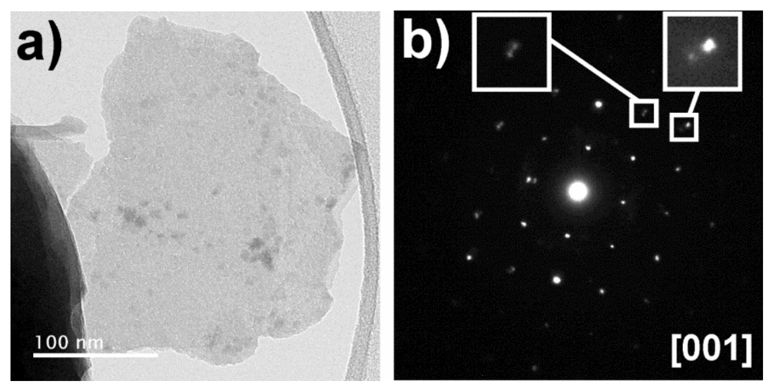
M. Vallet

### $[Ca_2Nb_3O_{10}]^-$ $TiO_2$




TEM

### In-plane view TEM





A. Grishin, B. Bérini, M. Vallet, S. Hurand, F. Maudet, C. Sartel, M. Frégnaux, S. Nowak, G. Amiri, S. Hassani, D. Aureau, V. Sallet, V. Demange, Y. Dumont. Appl. Surf. Science. 641 (2023) 158446

# Crystal size of the parent phase: $KCa_2Nb_3O_{10}$

**Molten salts:**

- Excess of $K_2CO_3$
- Growth temperature
- Cooling rate
- Salts: KCl, $K_2SO_4$, $K_2MoO_4$
- Ratio salt/precursors

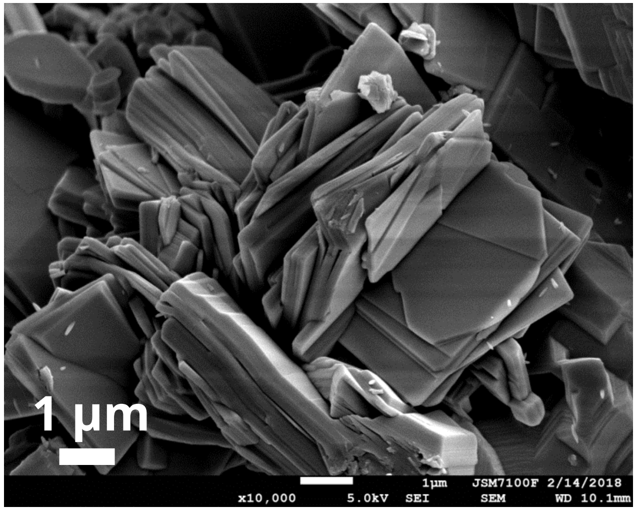
↓

**Pure phase**

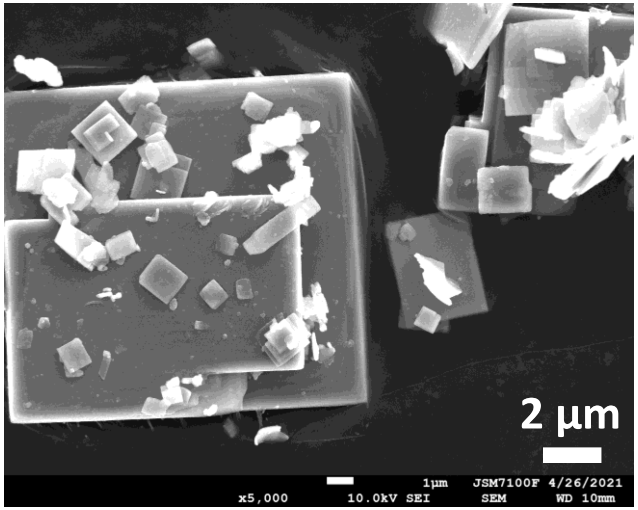
**Crystals size**

**Size distribution**

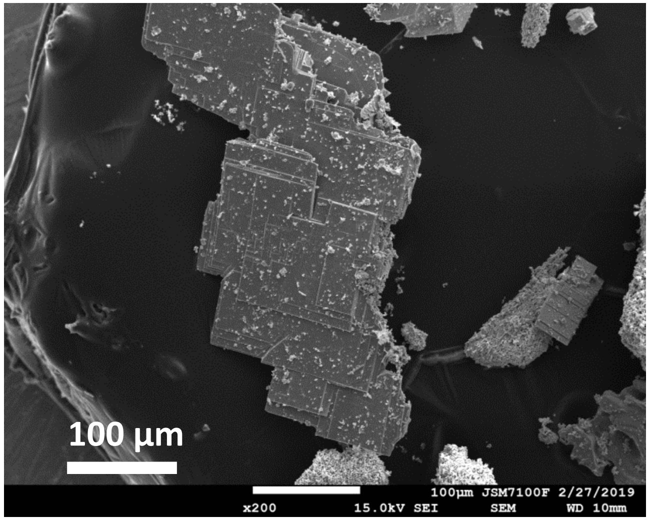
## Solid state reaction



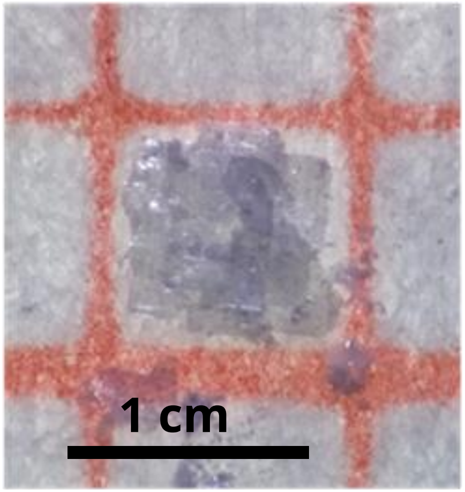

## Molten salt: $K_2SO_4$




## Molten salt: $K_2MoO_4$ (1)



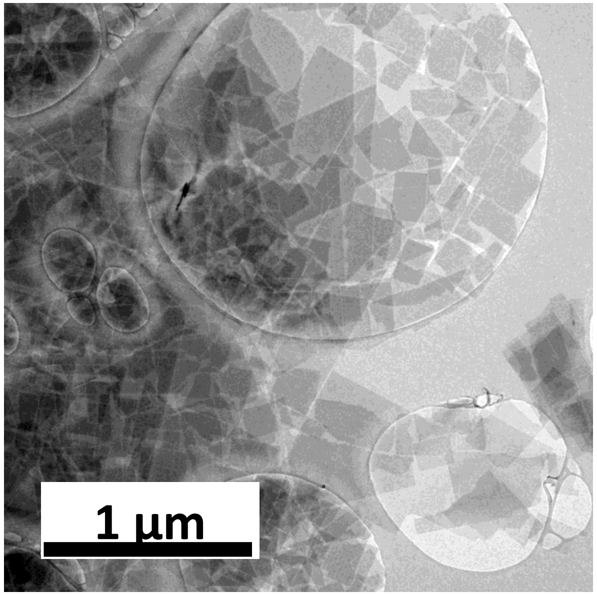

## Molten salt 2: $K_2MoO_4$ (2)



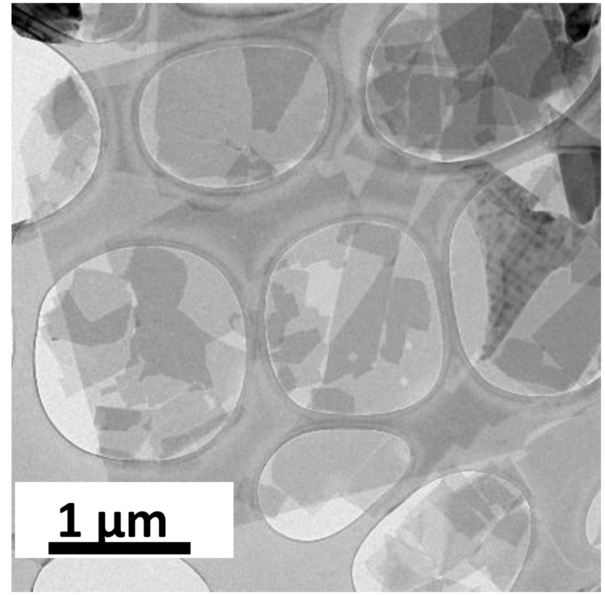
# Effect of growth methods of the parent phase on nanosheets size

**Solid state reaction**

~ 0.1 – 0.2 μm



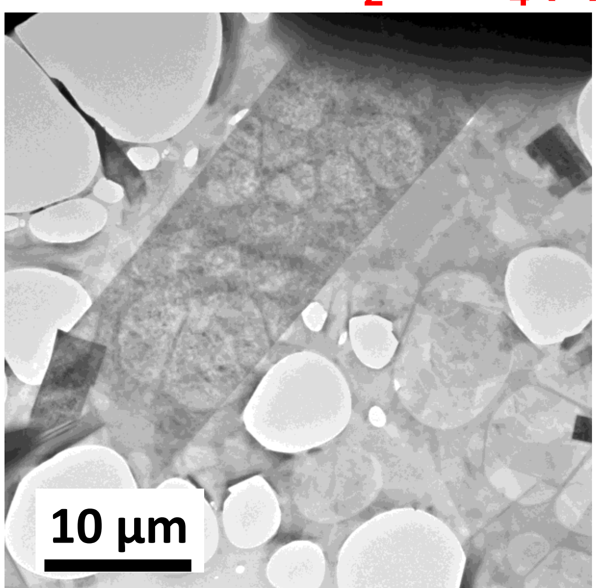

**Molten salt: $K_2SO_4$**



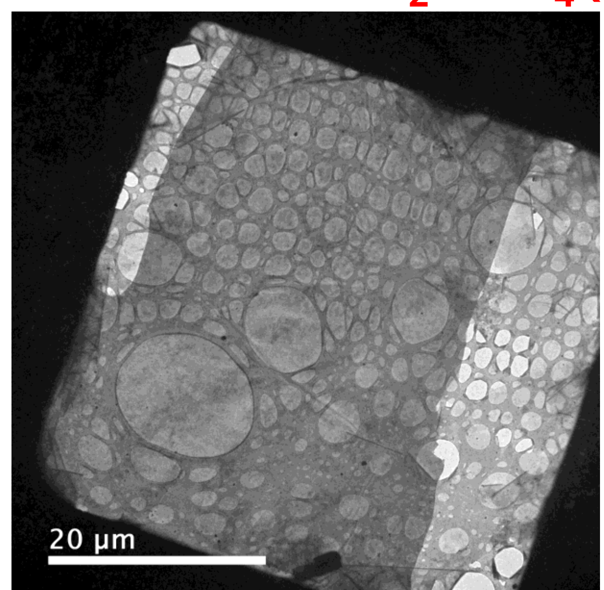

~ 2 – 5 μm

**Molten salt: $K_2MoO_4$ (1)**

~ 10 – 50 μm




**Molten salt 2: $K_2MoO_4$ (2)**

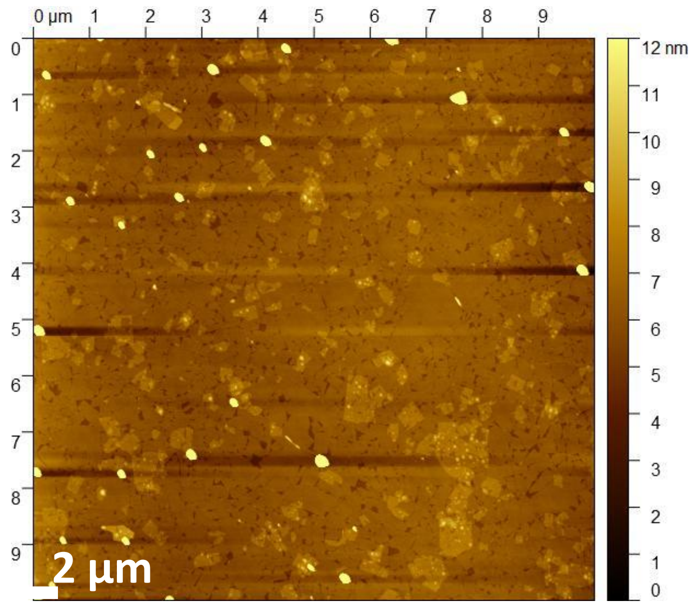



> 50 μm

# After transfer on substrates

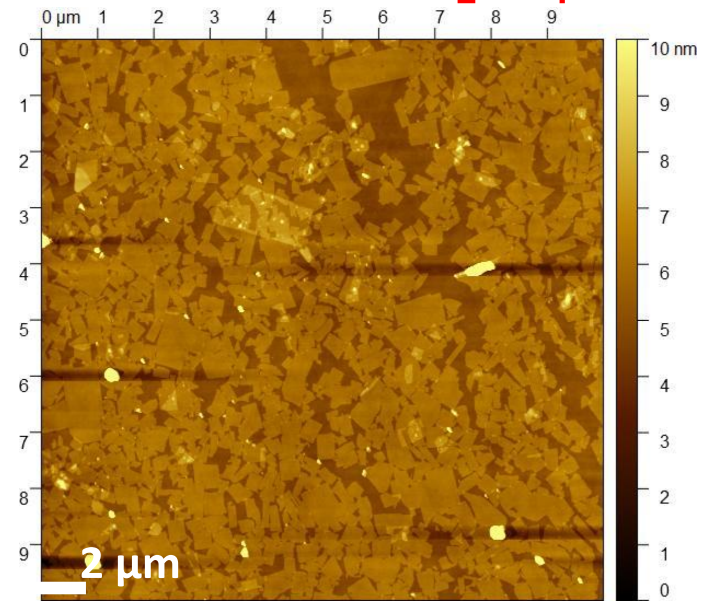
## Solid state reaction

~ 0.1 – 0.2 µm



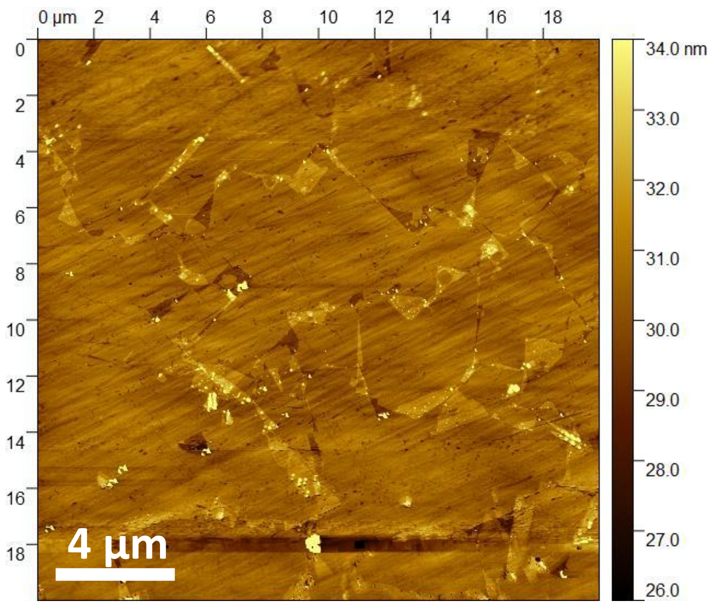

## Molten salt: $K_2SO_4$

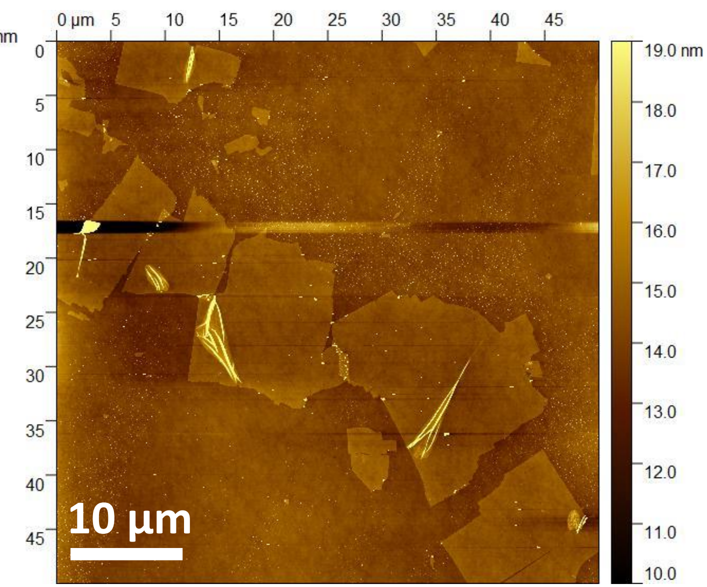
~ 0.2 – 0.5 µm




## Molten salt: $K_2MoO_4$ (1)

~ 5-20 µm



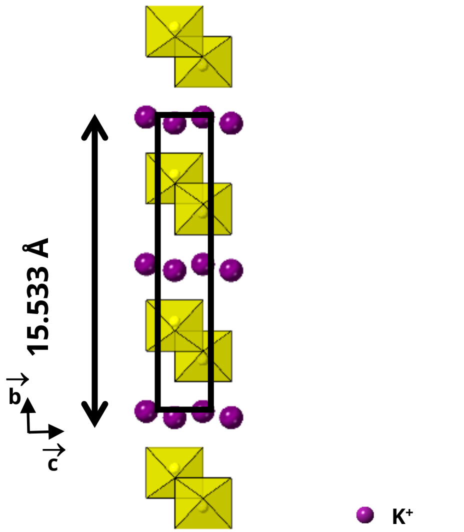




## Molten salt: $K_2MoO_4$ (2)

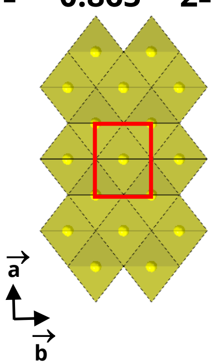
Drop casting doesn't work

# Other nanosheets for oxide growth

## $K_{0.8}Ti_{1.73}Li_{0.27}O_4$

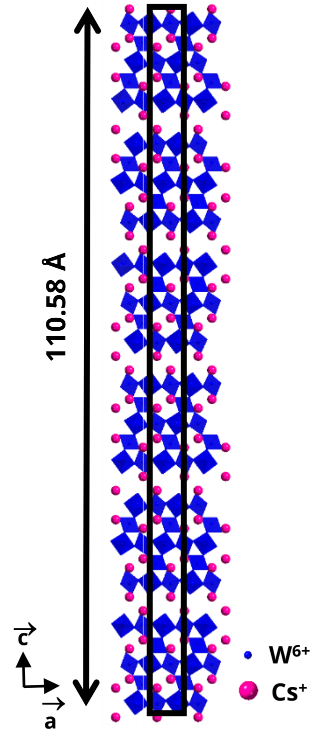



## $[Ti_{0.865}O_2]^{0.54-}$

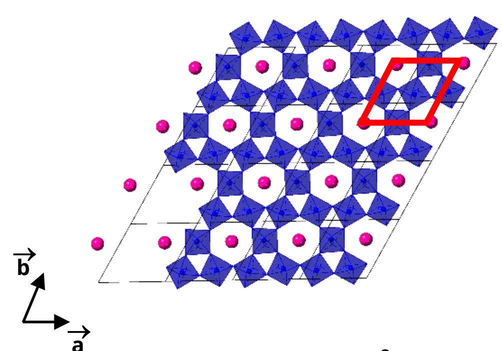



$a_{NS}$ ~ 3.82 Å
$c_{NS}$ ~ 2.97 Å

## $Cs_6W_{11}O_{36}$

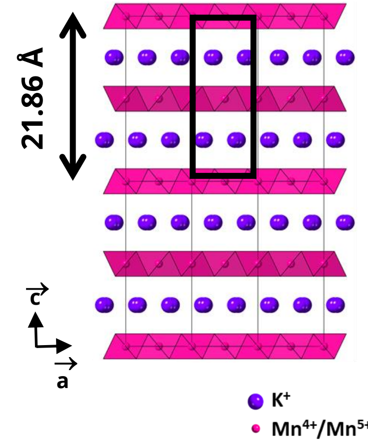



## $[Cs_4W_{11}O_{36}]^{2-}$

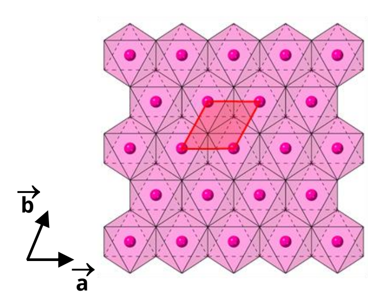



$a_{NS}$ = 7.261 Å

## $KMnO_2$
## $NaMoO_2$

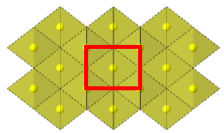
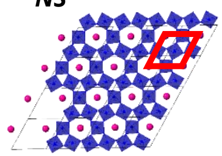
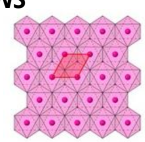



## $[\delta\text{-}MnO_2]^{0.4-}$
## $[\delta\text{-}MoO_2]^{0.4-}$



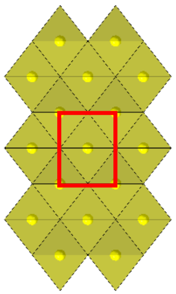

$a_{NS}$ = 2.94 Å

# Nanosheets for preferential orientation of oxides on any substrate

| Nanosheets (NS) | 2D lattice | Grown films on NS | Substrates |
|---|---|---|---|
| $[Ti_{0.87}O_2]^{0.52-}$ | Rectangle<br>$a_{NS}$ ~ 3.82 Å<br>$c_{NS}$ ~ 2.97 Å<br> | (110)$SrTiO_3$ | Glass |
| | | (110)$SrRuO_3$ | Si |
| | | (110)$Pb(Zr,Ti)O_3$ | Si, $Si_3N_4$ |
| | | (011)$VO_2$ | Si, Pt/$TiO_2$/Si |
| $[Cs_4W_{11}O_{36}]^{2-}$ | Hexagonal<br>$a_{NS}$ = 7.261 Å<br> | (001)ZnO | Glass, polymer |
| $[MnO_2]^{0.45-}$ | Hexagonal<br>$a_{NS}$ = 2.94 Å<br> | (001)ZnO | Glass |
| $[MoO_2]^{\delta-}$ | Hexagonal<br>$a_{NS}$ = 2.90 Å | (111)$SrTiO_3$ | Glass |
| $[NbWO_6]^{-}$ | Square<br>$a_{NS}$ = 4.68 Å x 4.68 Å | (-402)$VO_2$ | Si, $Si_3N_4$ |

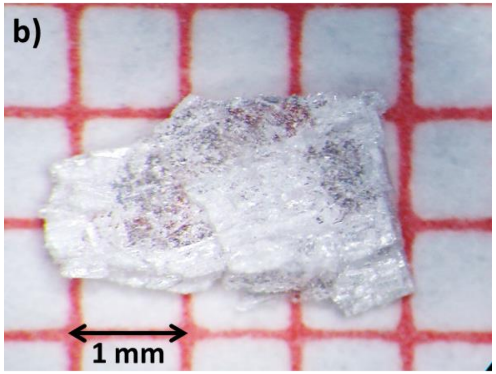
Refs: Sasaki's articles, Ten Elshof articles, …

# $[Ti_{0.865}O_2]^{0.54-}$ nanosheets for (110) perovskite growth

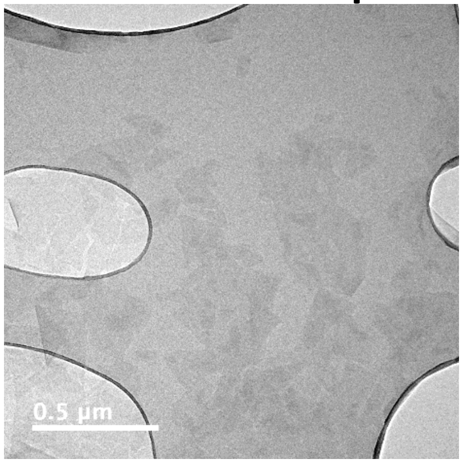


$a_{NS}$ ~ 3.82 Å
$c_{NS}$ ~ 2.97 Å

$K_{0.8}Ti_{1.73}Li_{0.27}O_4$



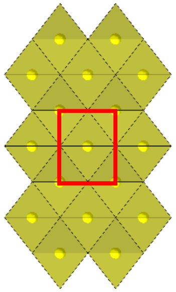

Size ~ 0.5 – 1 µm



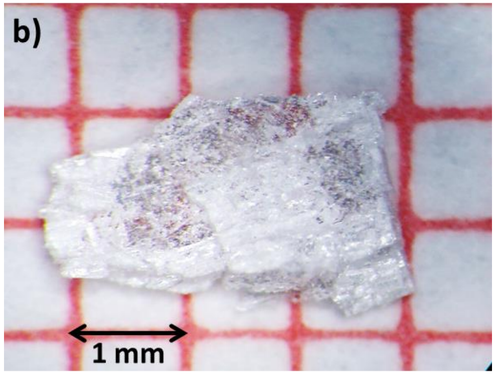
# $[Ti_{0.865}O_2]^{0.54-}$ nanosheets for (110) perovskite growth

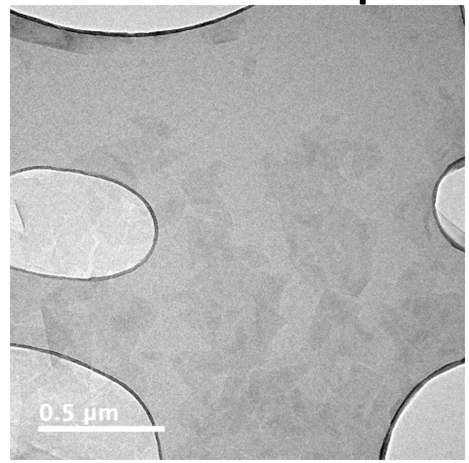
$K_{0.8}Ti_{1.73}Li_{0.27}O_4$

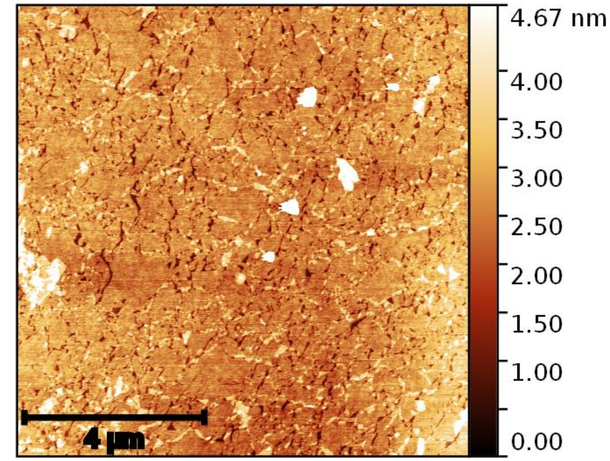
Size ~ 0.5 – 1 µm



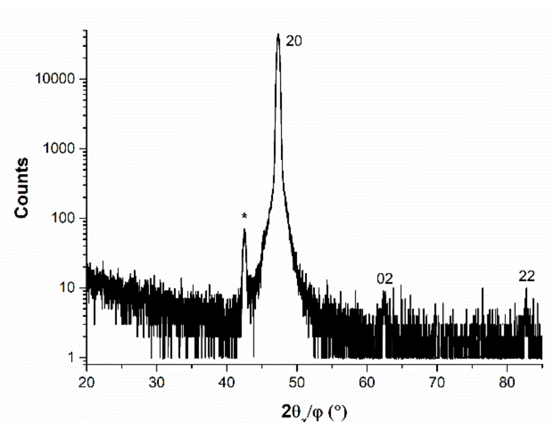
$a_{NS}$ ~ 3.82 Å
$c_{NS}$ ~ 2.97 Å



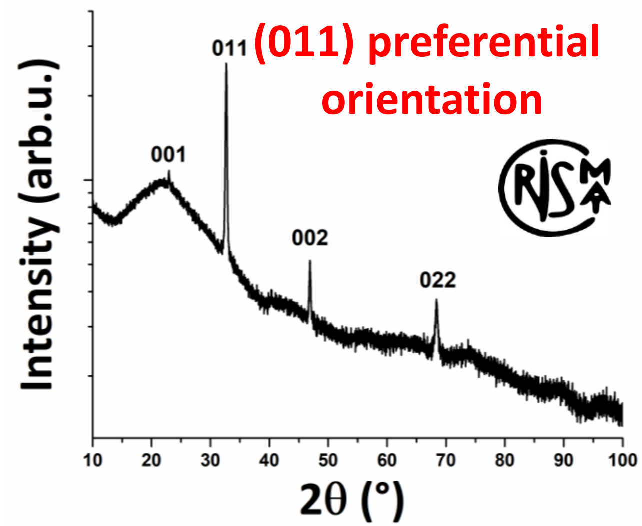

## In-plane XRD



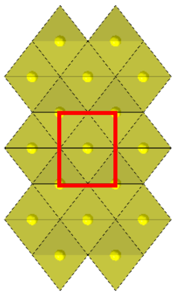

*a* = 3.84 Å
*c* = 2.97 Å

*: $K_\beta$ line of the 20 reflection

## Growth of $La_{0.67}Sr_{0.33}MnO_3$ on $[Ti_{0.865}O_2]^{0.54-}$ /glass

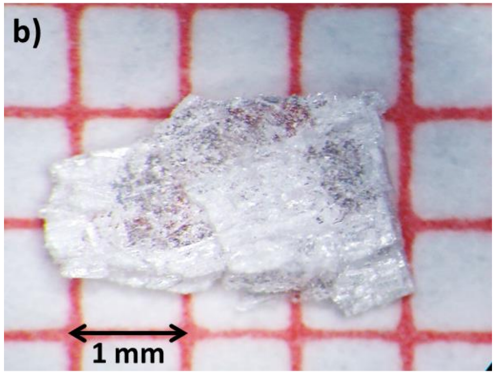


# $[Ti_{0.865}O_2]^{0.54-}$ nanosheets for (110) perovskite growth

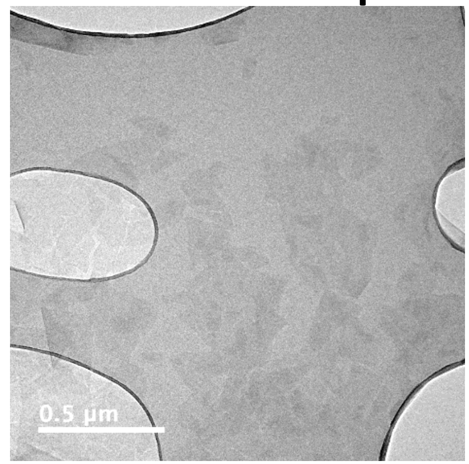


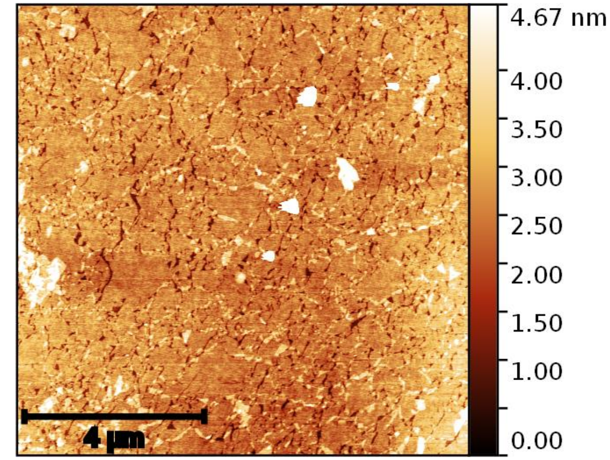
$a_{NS}$ ~ 3.82 Å
$c_{NS}$ ~ 2.97 Å

$K_{0.8}Ti_{1.73}Li_{0.27}O_4$

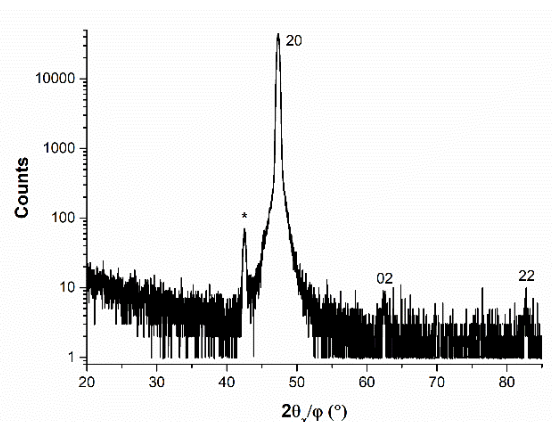



Size ~ 0.5 – 1 µm



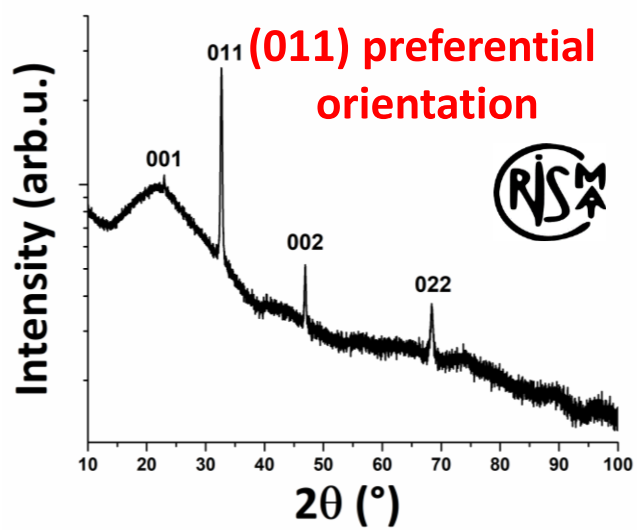

## In-plane XRD



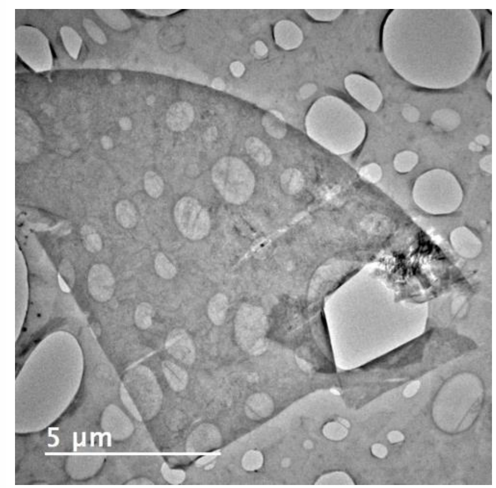

*a* = 3.84 Å
*c* = 2.97 Å

*: $K_\beta$ line of the 20 reflection

## Growth of $La_{0.67}Sr_{0.33}MnO_3$ on $[Ti_{0.865}O_2]^{0.54-}$ /glass

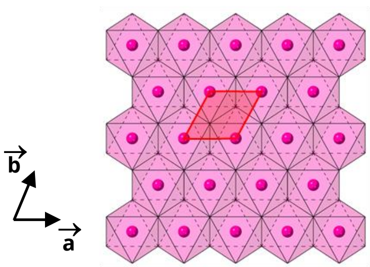



## $[(Ti,Co,Fe)_{0.865}O_2]^{0.54-}$



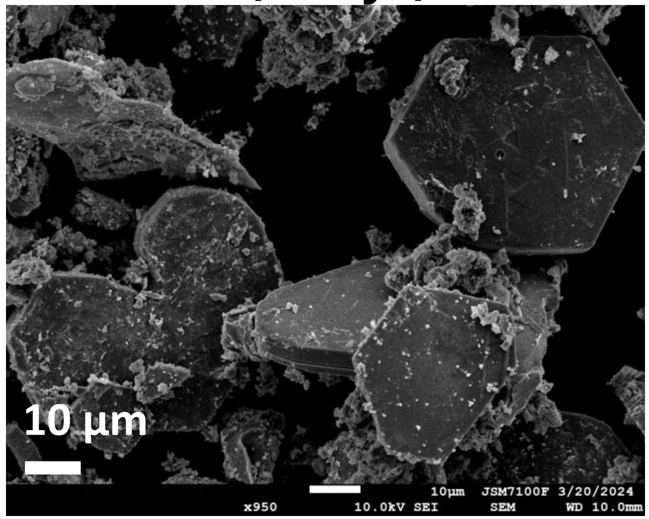
# $[MnO_2]^{0.45-}$ nanosheets for (111) perovskite growth

~~$NaMoO_2$~~

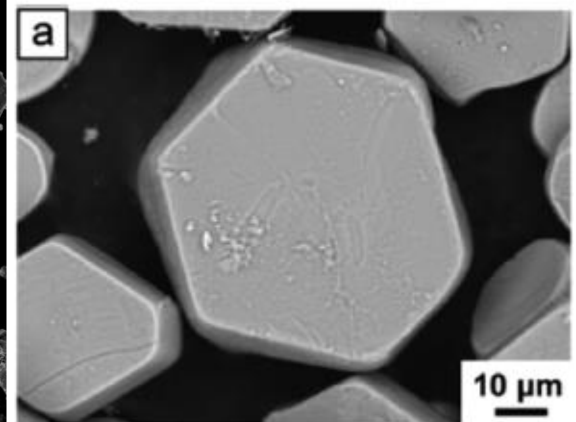



$a_{NS}$ = 2.94 Å

**$KMnO_2$**
**(4 days)**




**Yano *et al.***
**(3 months)**



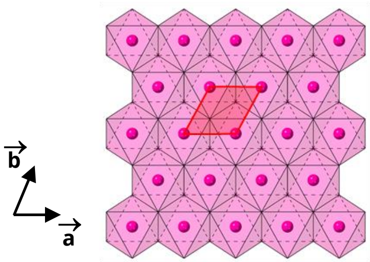

Yano *et al*. Cryst. Growth Des. (2022) 22

**See Sahar Gaddour's poster**

**Master 2**

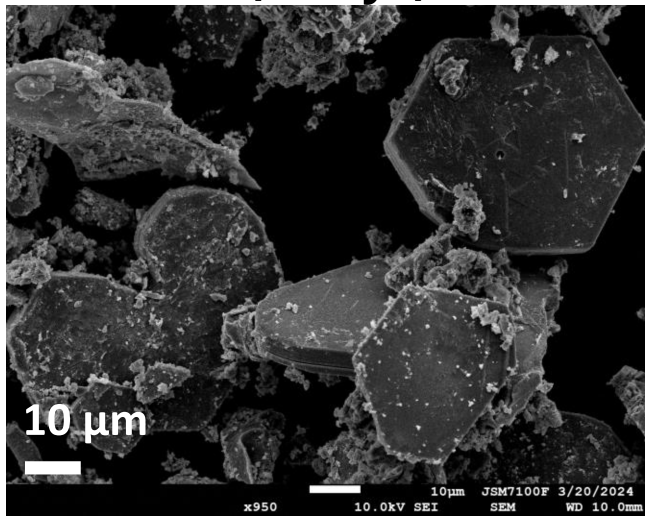
# $[MnO_2]^{0.45-}$ nanosheets for (111) perovskite growth

~~$NaMoO_2$~~

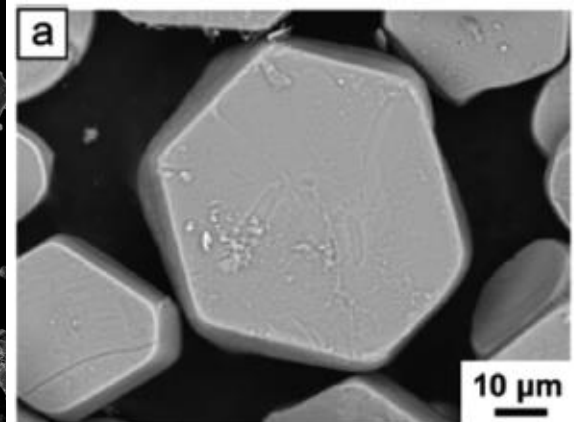



$a_{NS}$ = 2.94 Å

**KMnO$_2$ (4 days)**




**Yano *et al.* (3 months)**

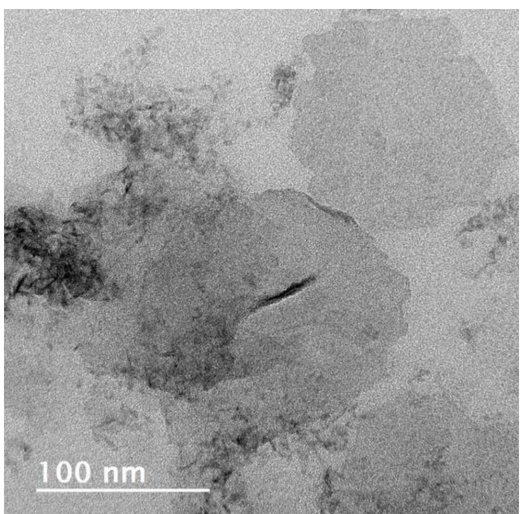


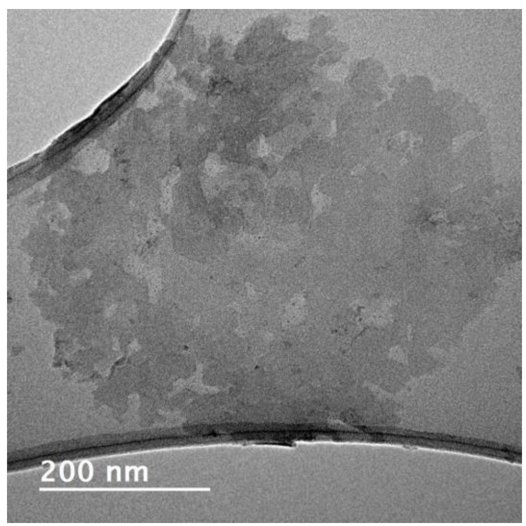

Yano *et al*. Cryst. Growth Des. (2022) 22

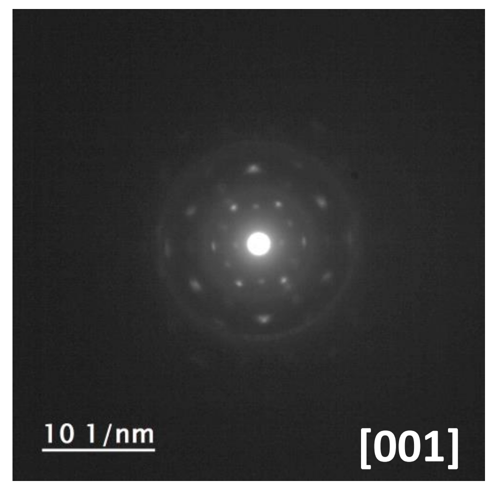
See Sahar Gaddour's poster

Master 2

**First attempt of exfoliation**




**TEM**

Institut des Sciences Chimiques de Rennes UMR CNRS 6226

L. Rault

# Conclusions

- Integration of various oxides (including oxides that react with Si) on Si and glass thanks to nanosheets

- Excellent properties of thin films grown on Si or glass

- Easy process, large surface

- Synthesized nanosheets:

$[Ca_2Nb_3O_{10}]^-$, $[Sr_2Nb_3O_{10}]^-$, $[Ti_{0.865}O_2]^{0.54-}$, $[MnO_2]^{0.45-}$

and also : $[K_{4-x}Nb_6O_{17}]^{x-}$, $[Cs_4W_{11}O_{36}]^{2-}$, $[(Ti,Co,Fe)_{0.865}O_2]^{0.54-}$

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"Flexo" ANR ANR-21-CE09-0046

"DisTCOvery" ANR-23-CE08-0008-05