Alpha-Al_2O_3 Nanotemplate as a Novel Method of Improving the Oxidation Life of Thermal Barrier Coatings

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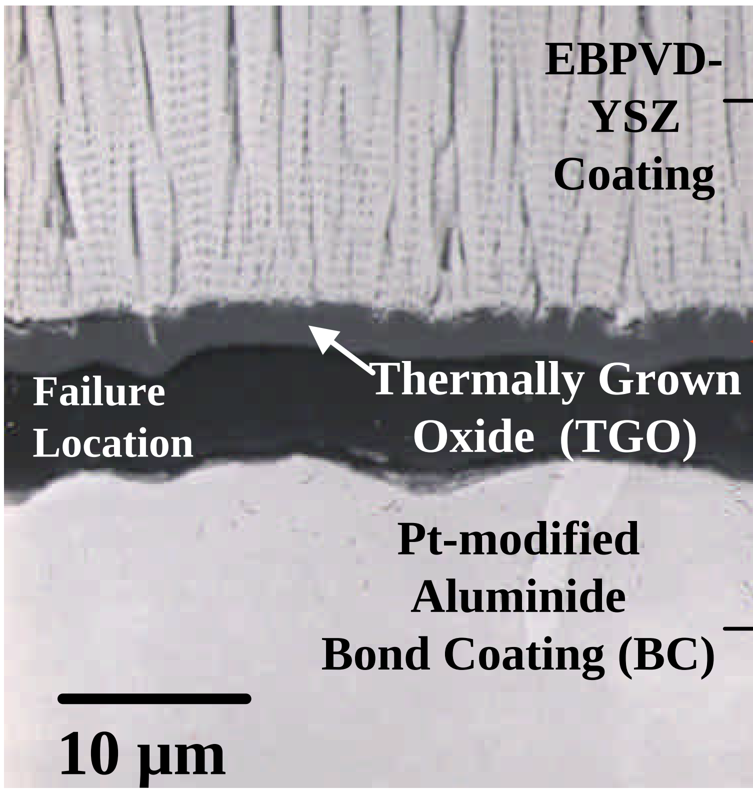
Abstract

We are exploring a novel concept that will improve the oxidation life of thermal barrier coatings (TBCs) while reducing the non-load-bearing weight of TBC-coated turbine components. TBCs are currently used, in conjunction with air cooling, to prolong the life of metallic "hot-section" Ni-based superalloy components used in aircraft engines and power generation turbines with an annual market size of ~$1.5 billion. The life of state-of-the-art TBCs is largely dictated by: (1) the ability of a metallic bond coating to form an adherent scale, or commonly referred to as thermally grown oxide (TGO), at the metal-ceramic interface and (2) the rate at which the TGO grows upon high-temperature oxidation. Metallic bond coatings, despite their critical importance to current TBC design, contribute significant "dead weight" to thin-walled turbine components, and exhibit serious chemical and mechanical instabilities at the substrate/bond coating/TGO interfaces during long-term exposures.

We have discovered a novel procedure for preparing a ~100 nm thick nanotemplate of fully crystalline α-Al_2O_3 directly on the surface of a single crystal Ni-based superalloy by chemical vapor deposition. The α-Al_2O_3 nanotemplate reduces the rate of TGO growth by a factor of three through the elimination of transient oxidation and the formation of less grain boundaries within the columnar TGO structure upon oxidation at 1150°C for 50 hours. Our results demonstrate that the α-Al_2O_3 nanotemplate proactively guides the alloy surface to form a TGO that is more tenacious and slower growing than what is attainable with state-of-the-art bond coatings, and consequently offers the realistic chance of eliminating the need for a thick, non-load-bearing metallic coating in future TBC design.

How to Engineer TGO beyond Traditional Metallurgical Methods?



Weakest Link (7 mm)

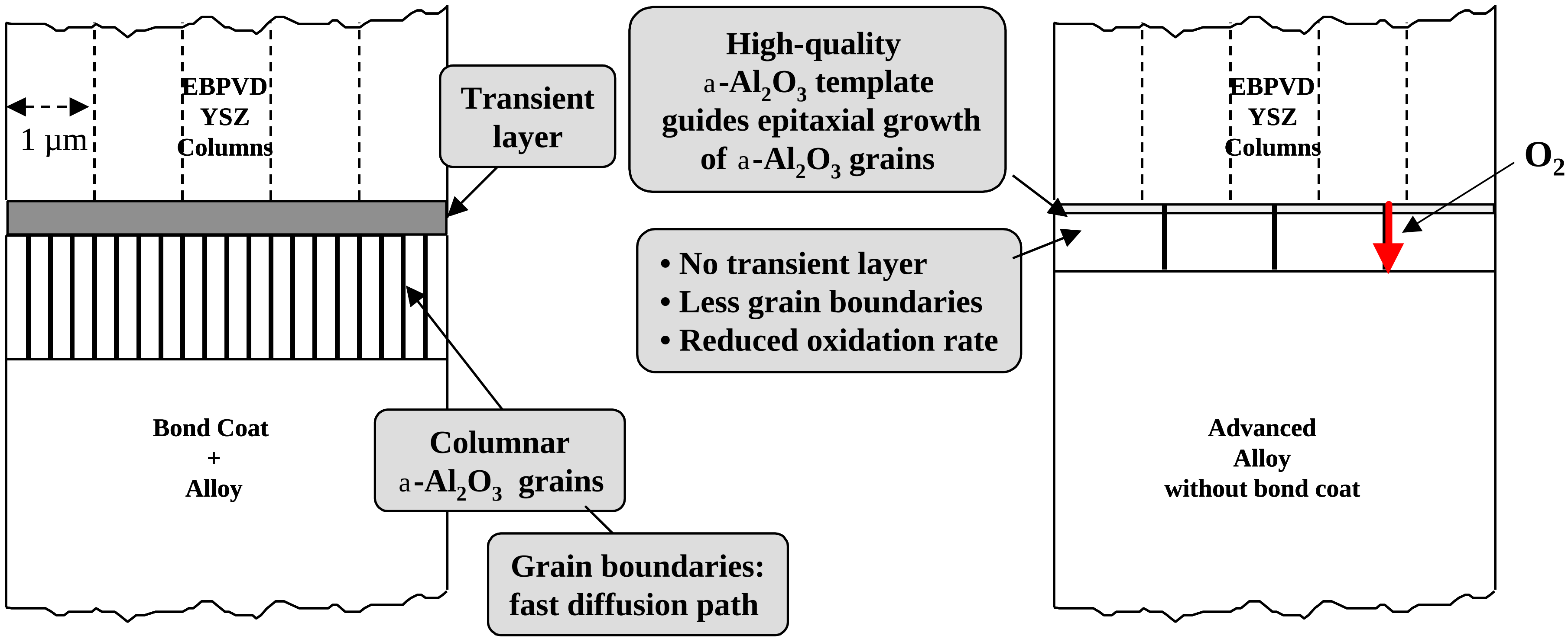
Primary Functionality		Tailorable Properties

- **Thermal Insulation** (EBPVD-YSZ Coating →)
  - **Low k**
    - k
    - Defects
  - **Strain Tolerance**
    - Microstructure
    - CTE match
  - **Stability**
    - Erosion
    - Corrosion
    - Sintering
    - TGO interface
- **Oxidation Resistance** (Pt-modified Aluminide Bond Coating (BC) →)
  - **TGO Adhesion**
    - Oxidation kinetics
    - Impurity segregation
    - Morphology
    - Dopants
  - **BC Stability**
    - Creep resistance
    - Grain boundaries
    - Interdiffusion
    - Phase transformations
    - Dopants

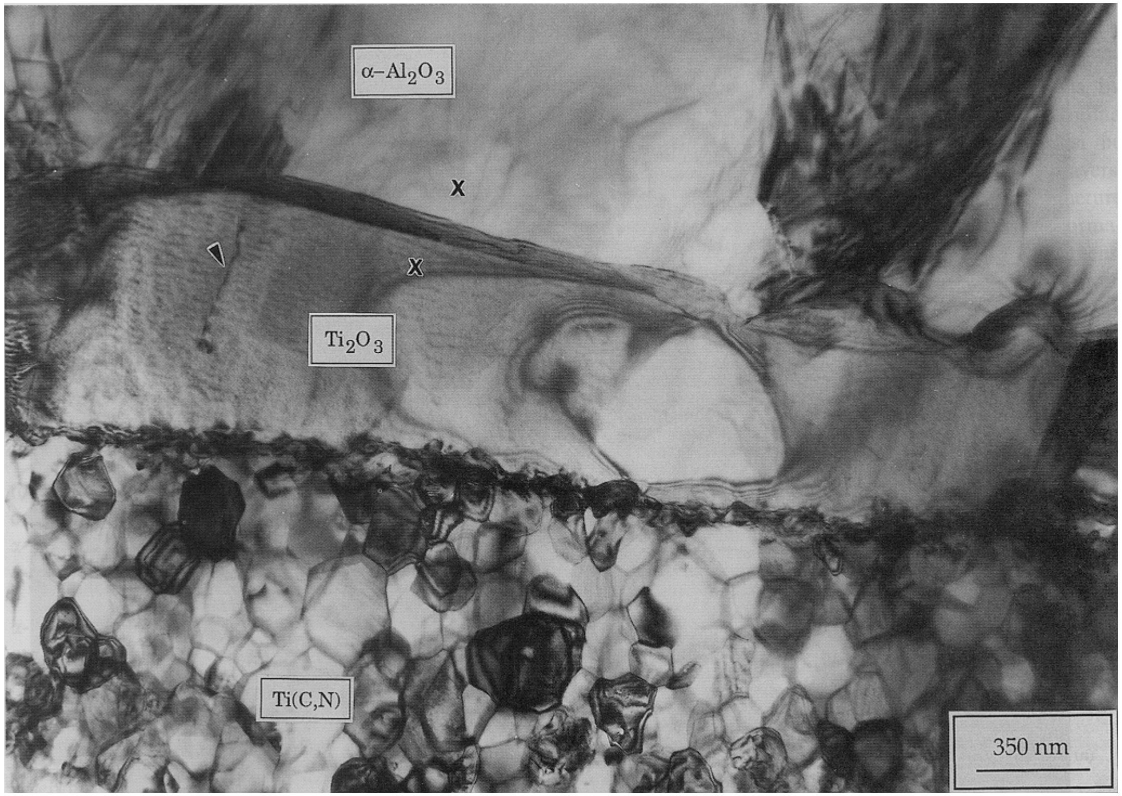
Nanotemplate Approach Offers Slower TGO Growth and Bond Coat Elimination

Passive TGO Formation

Proactive TGO Engineering



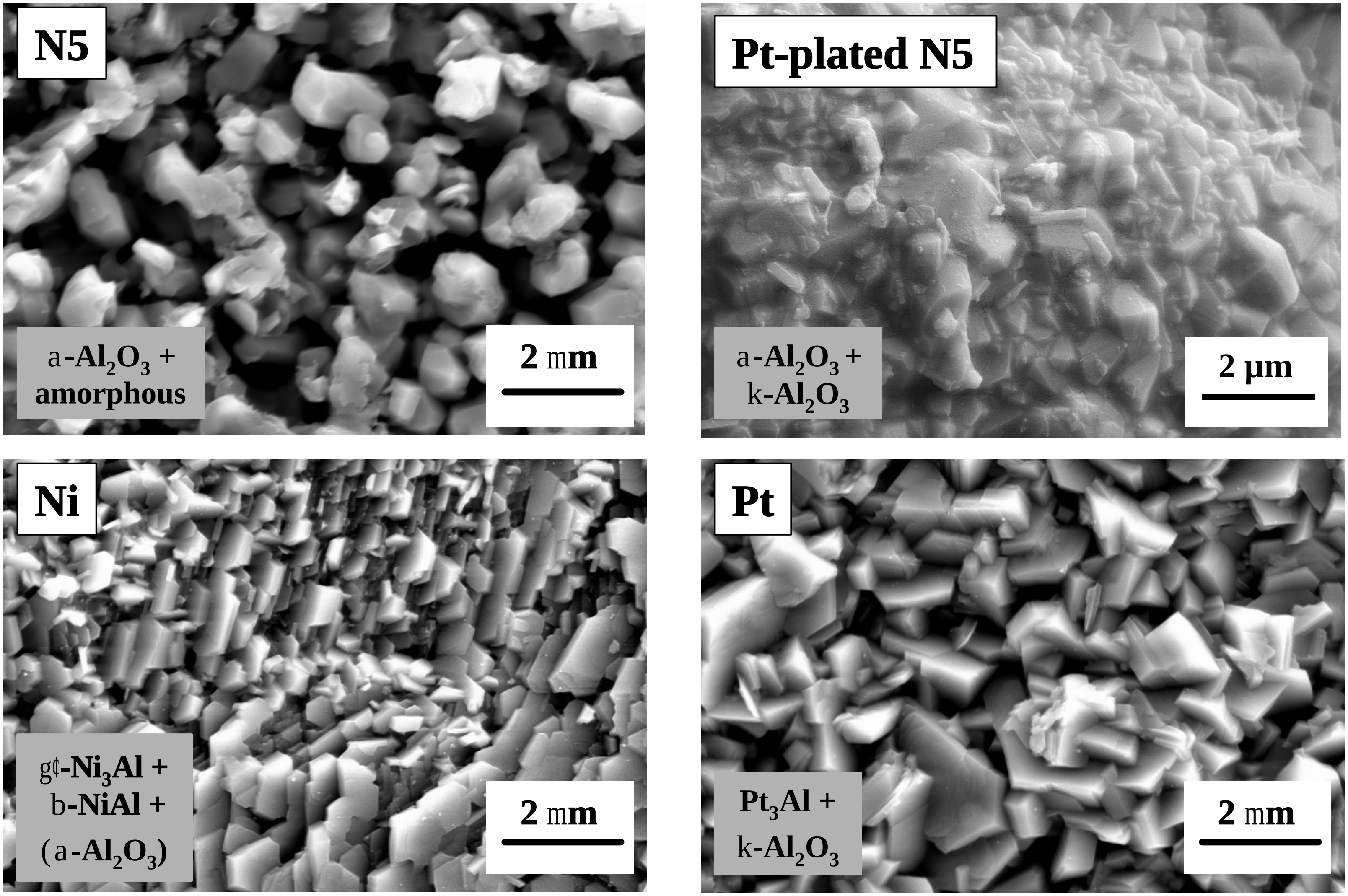
Industry CVD Process Was Initially Examined for a-Al_2O_3 Nanotemplate Synthesis



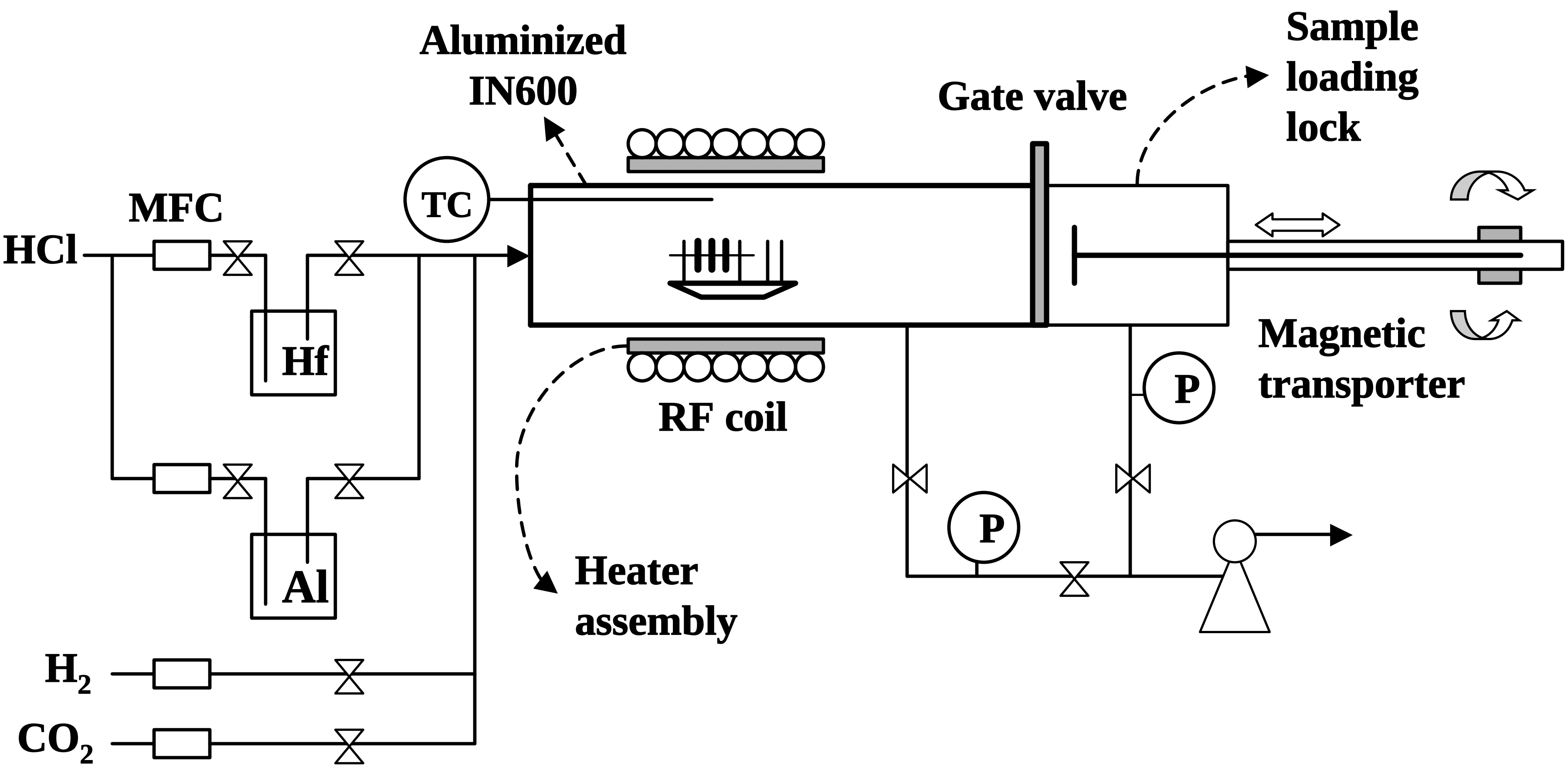
Halvarsson & Vuorinen, 1995

- **SECO Tools**
- **$AlCl_3/H_2/CO_2$**
- **1020°C for 3 h**

Substrates Effects on As-Deposited CVD-Al_2O_3 Morphology



Laboratory CVD Reactor
Used at Stevens to Optimize CVD a-Al_2O_3

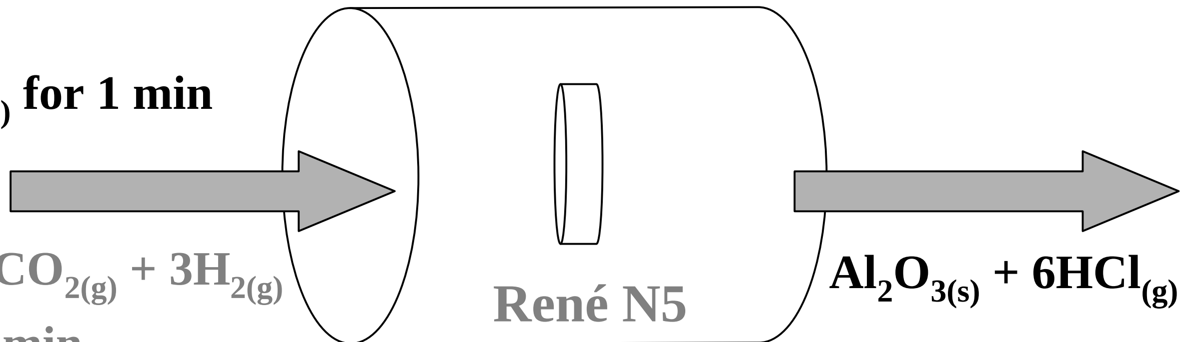


$CO_2 + H_2$ Pretreatment for Short-Time Selective Oxidation

1050°C, 10 torr

Step 1. $CO_{2\,(g)} + H_{2\,(g)}$ **for 1 min**

Step 2. $2AlCl_{3(g)} + 3CO_{2(g)} + 3H_{2(g)}$ **for 10 min**



$Al_2O_{3(s)} + 6HCl_{(g)} + 3CO_{(g)}$

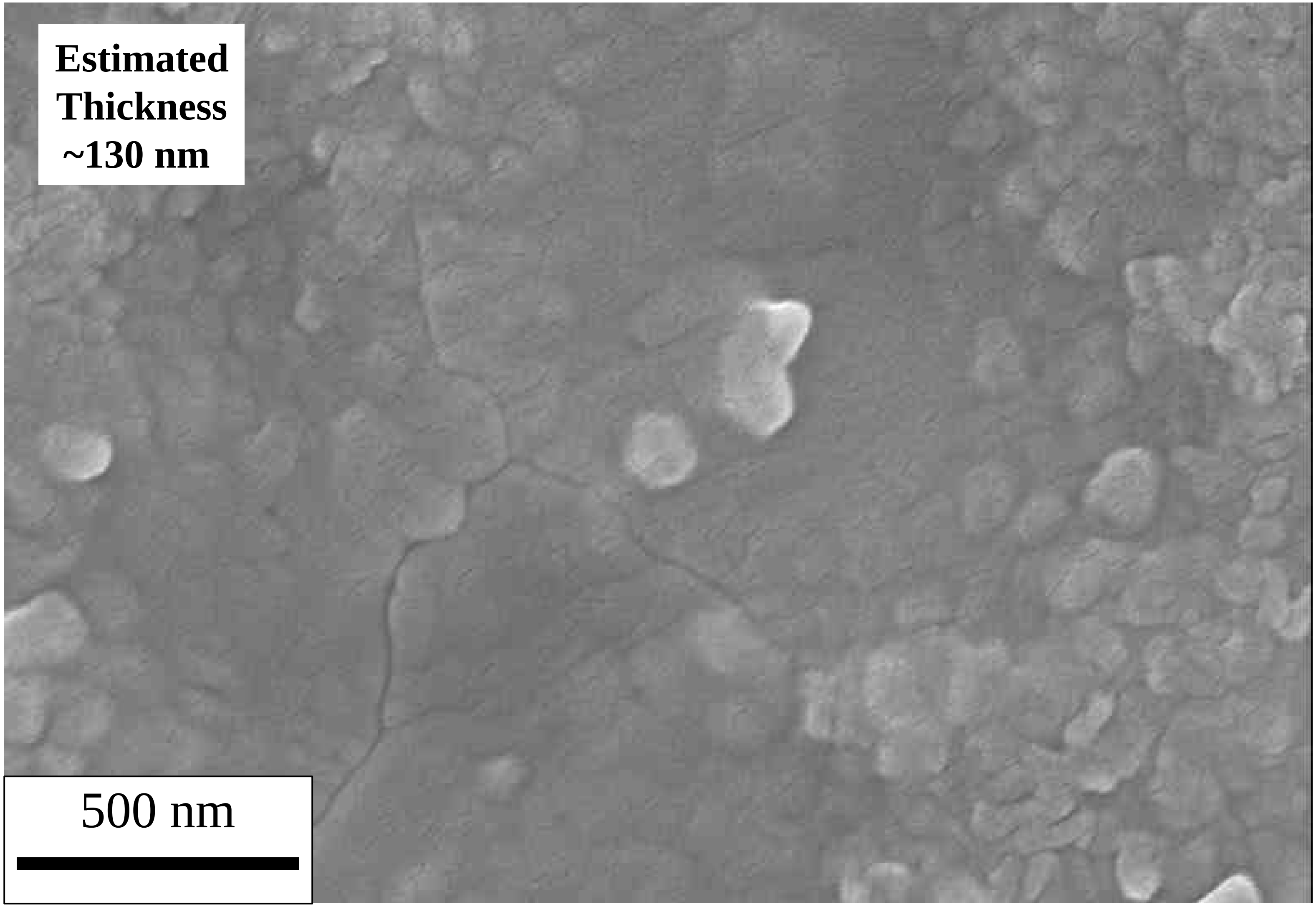
$CO_{2(g)} + H_{2(g)} = H_2O_{(g)} + CO_{(g)}$

$$P_{O_2}^{eq} = \sim 10^{-8}\ torr$$

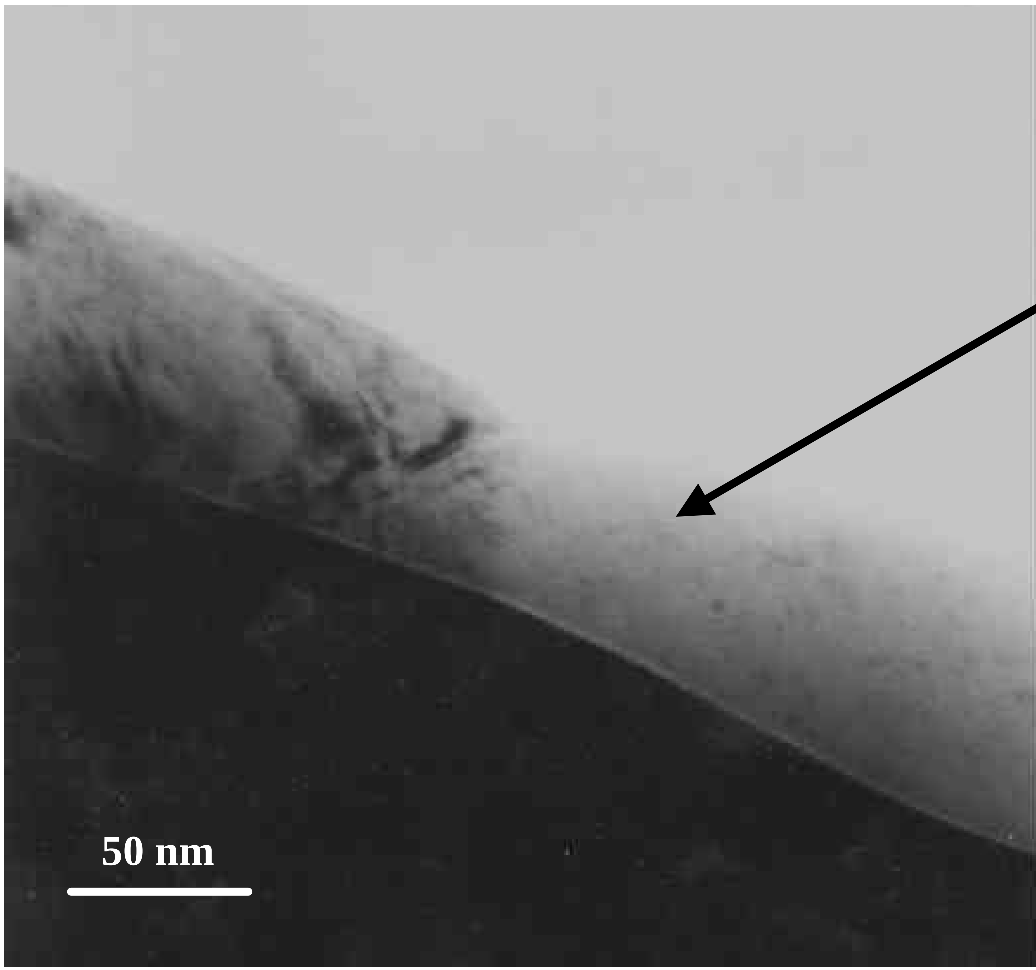
$$P_{H_2O}^{eq} = \sim 1\ torr$$

$$P_{H_2O}^{actual} << P_{H_2O}^{eq}$$

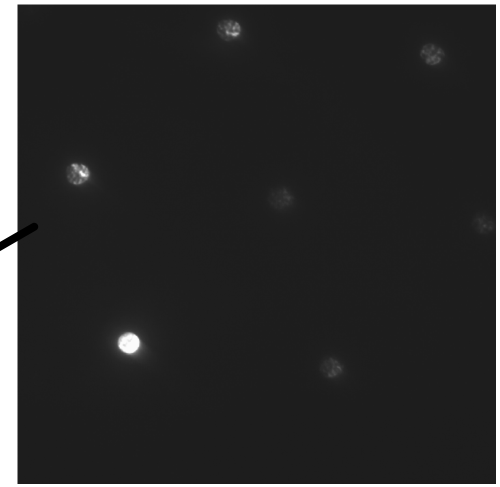
Surface Morphology after 1 min CO_2+H_2 & 10 min CVD-Al_2O_3 on René N5



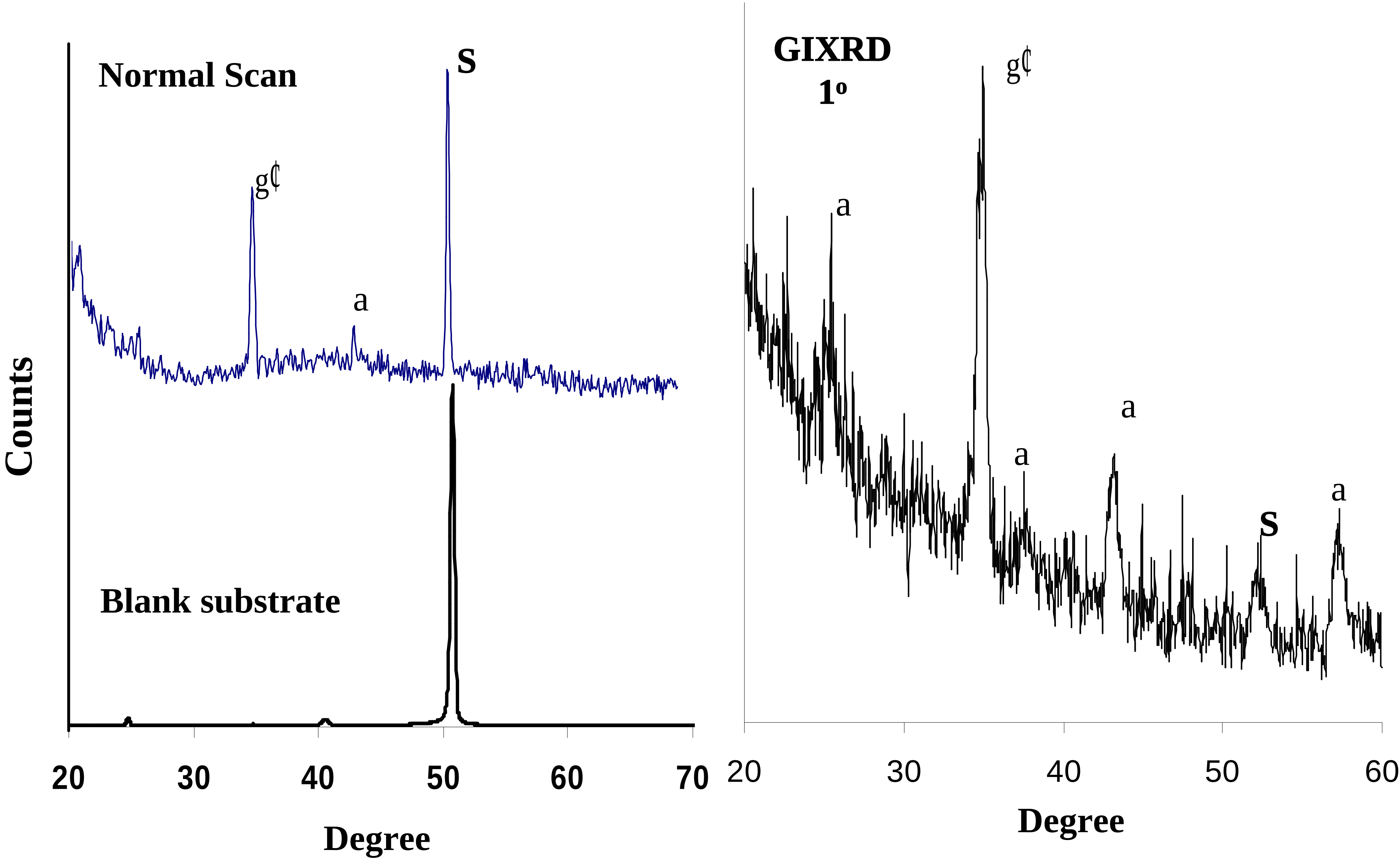
Continuous and Homogeneous a-Al_2O_3 Layer (~50 to 150 nm)



$[1\bar{1}01]$

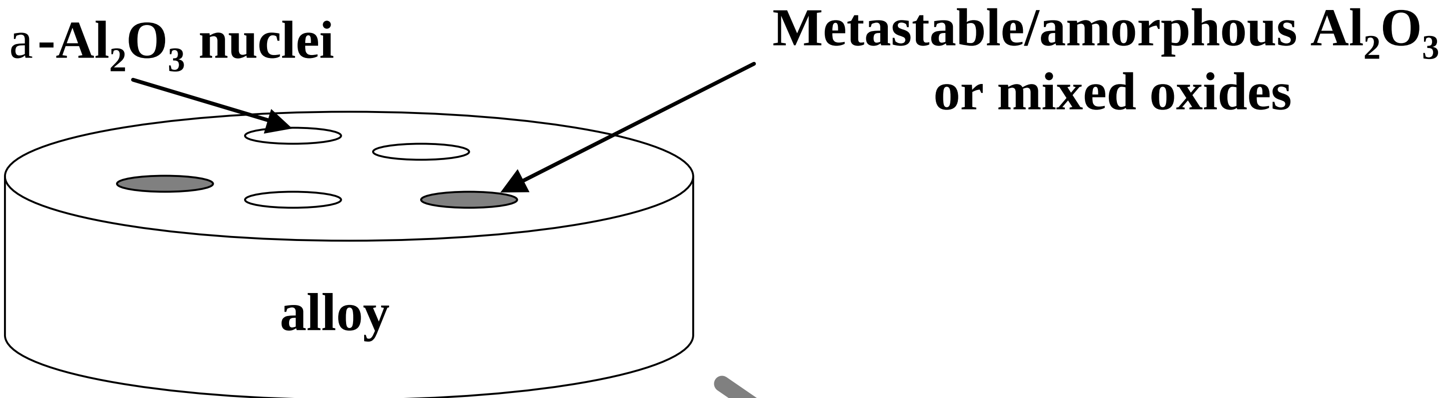


a-Al_2O_3 Detected Along With Polycrystalline g¢-Ni_3Al

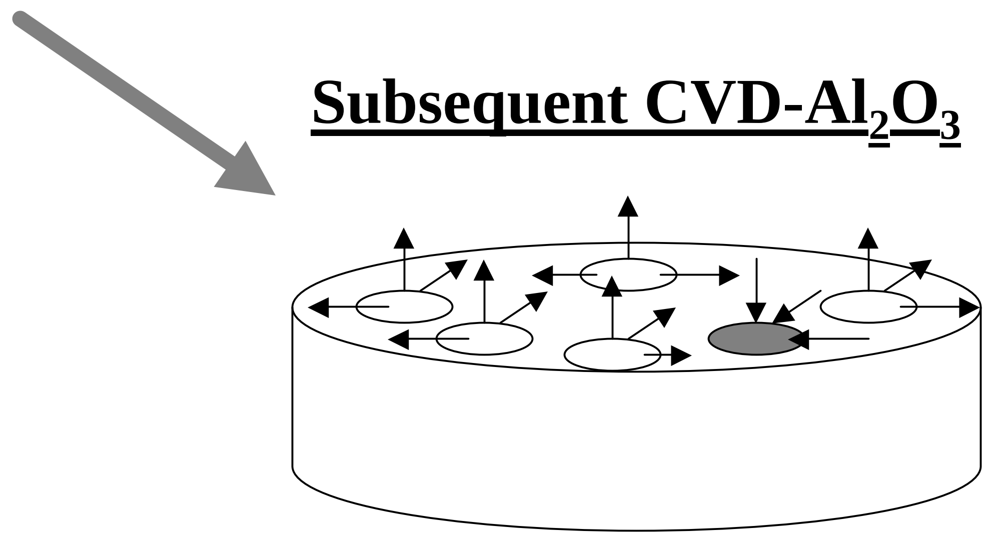


Our Speculation on Effects of CO_2+H_2 Pretreatment

After CO_2 + H_2 Pretreatment

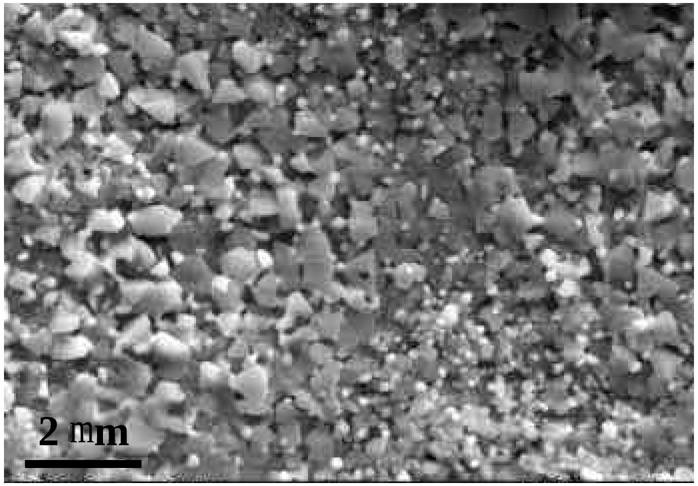


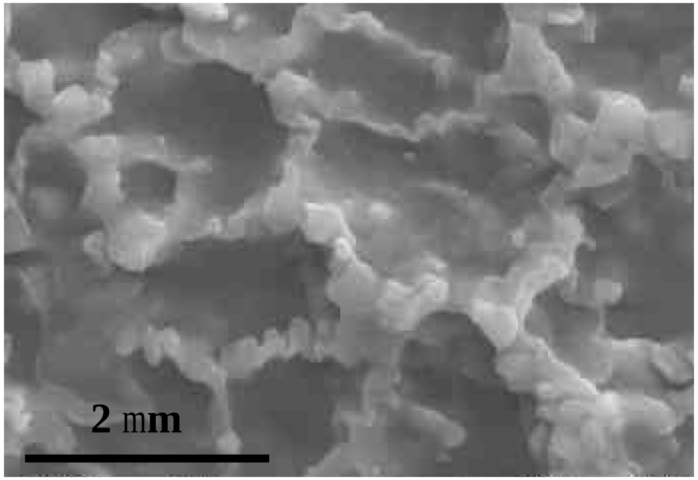
Subsequent CVD-Al_2O_3



Effects of Nanotemplate on TGO Morphology & Growth

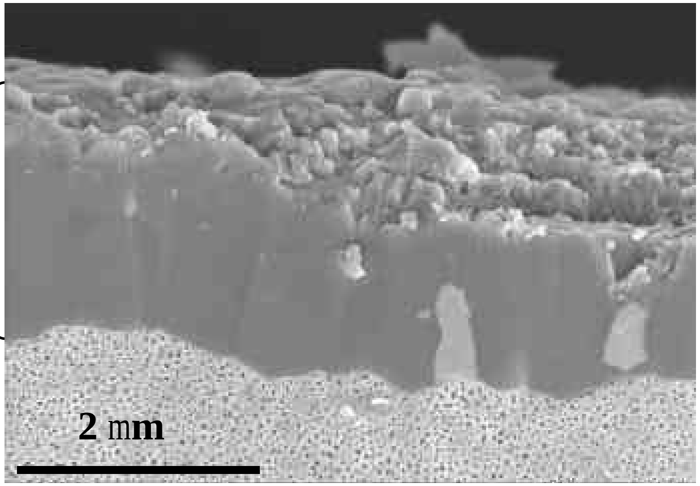
without nanotemplate | **with nanotemplate**

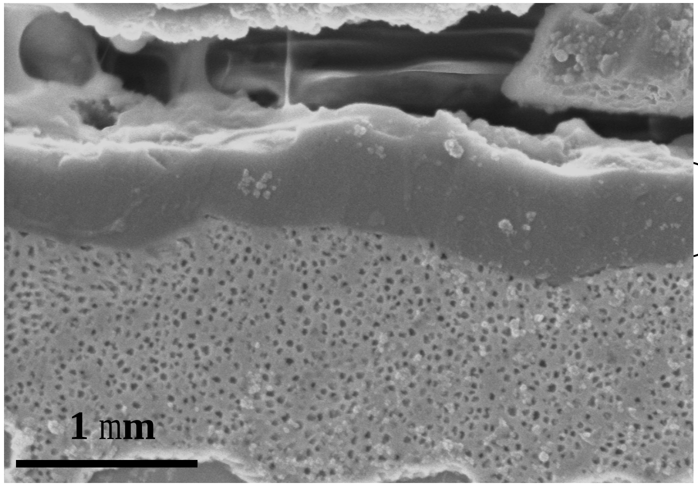




~ 2.1 μm
TGO

René N5





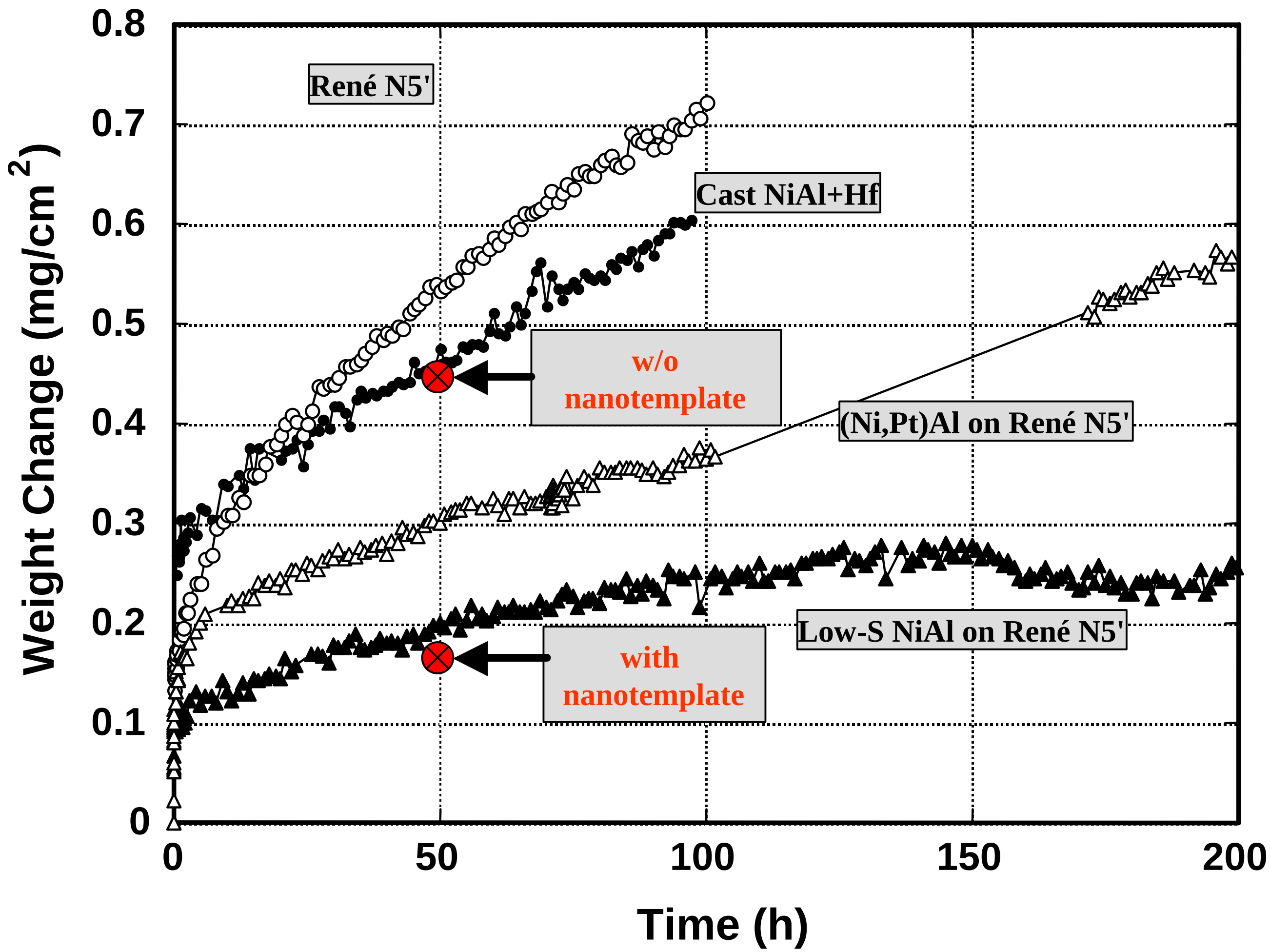
Epoxy

~ 0.7 μm
TGO

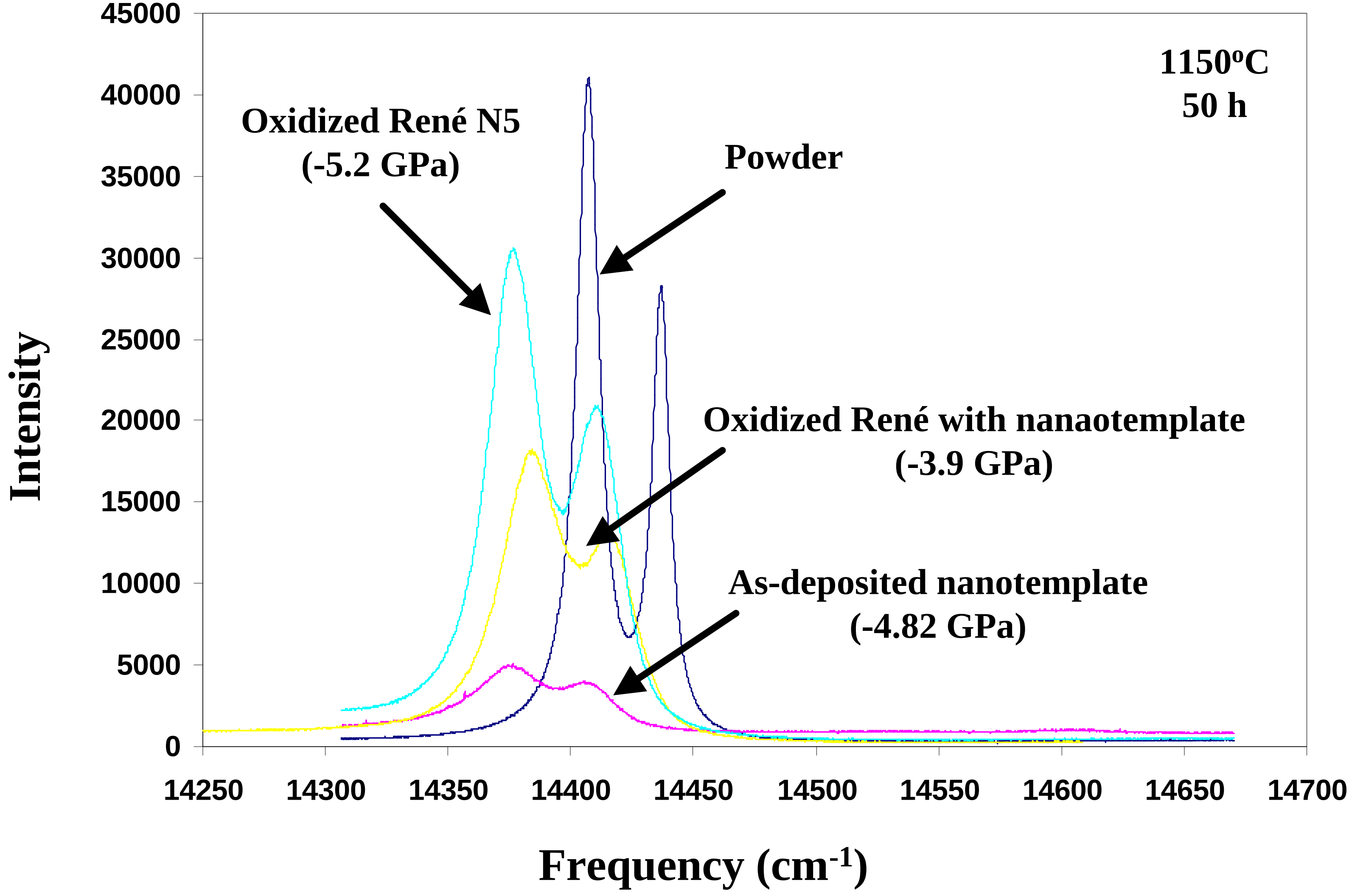
René N5

After Isothermal Oxidation at 1150°C for 50 h

Effectiveness of Nanotemplate in Comparison to Advanced Alloys and Bond Coatings



Nanotemplate/TGO Was Highly Stressed before and after Oxidation



Conclusions

- **Synthesis of an entirely a-Al_2O_3 nanotemplate layer directly on René N5 appears to be possible.**

- **The TGO on René N5 grows about three times slower with a 100 nm nanotemplate during isothermal oxidation at 1150^{o}C for 50 hours.**
  - **Predominately inward TGO growth**
  - **No transient oxidation (TBD)**
  - **Less number of grain boundaries (TBD)**

- **The TGO is highly stressed to about -4 GPa after the oxidation exposure indicating that the quality of the TGO is excellent.**