Development of Improved Powder for Bonded Permanent Magnets: Surface passivation

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Project Objectives:

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- Develop high performance permanent magnets (PM) for traction motor with internal PM rotor :
  - requires elevated temperature (180-200˚C) operation, minimize cooling needs
  - increased high temperature magnetic performance more critical than RT
- Reduce manufacturing cost of PM traction motors:
  - bonded PM can utilize injection or compression molding technology
    - net shape forming for mass production of rotors
- Achieve high performance and reliability for bonded magnets:
  - increase volumetric loading
  - minimize irreversible magnetic losses (oxidation)

Requirement for Surface Passivation

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- Rare Earth – Iron – Boron magnet alloys
  - Oxidize easily
    - Reduces volume of magnet material
    - Explosion hazard for fine particles
  - React with binder material
  - Corrode over time
- Require and effective surface coating
  - Nanometers thick
  - In situ application

Magnet Production Techniques

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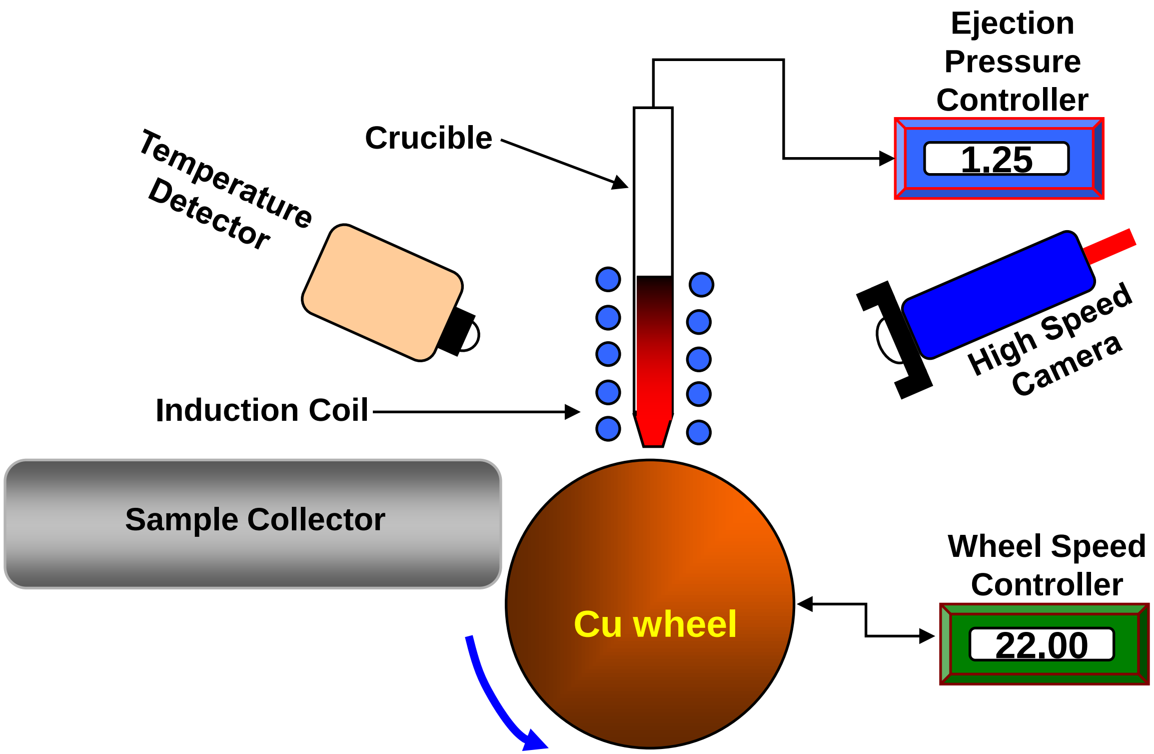
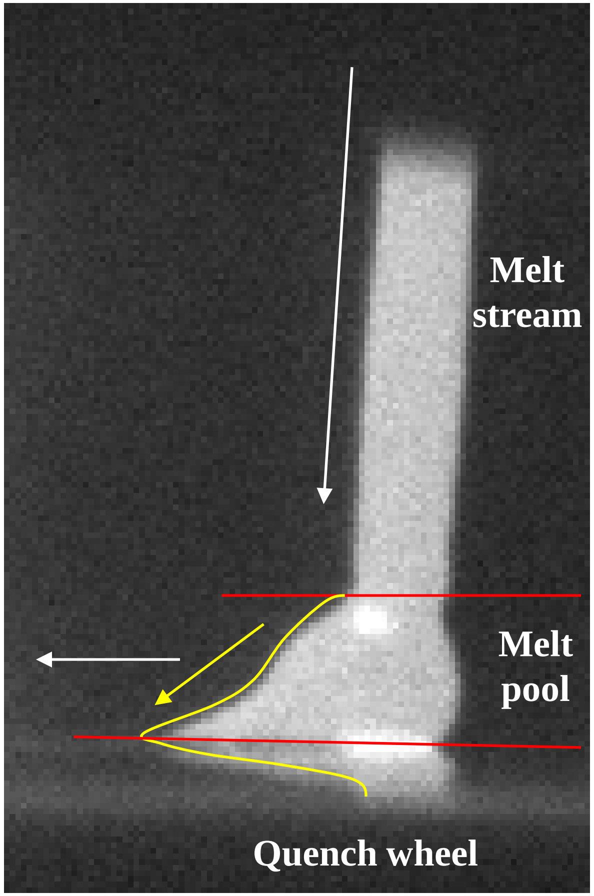
Melt Spinning Technique





Full instrumented coating system for optimization of coating process

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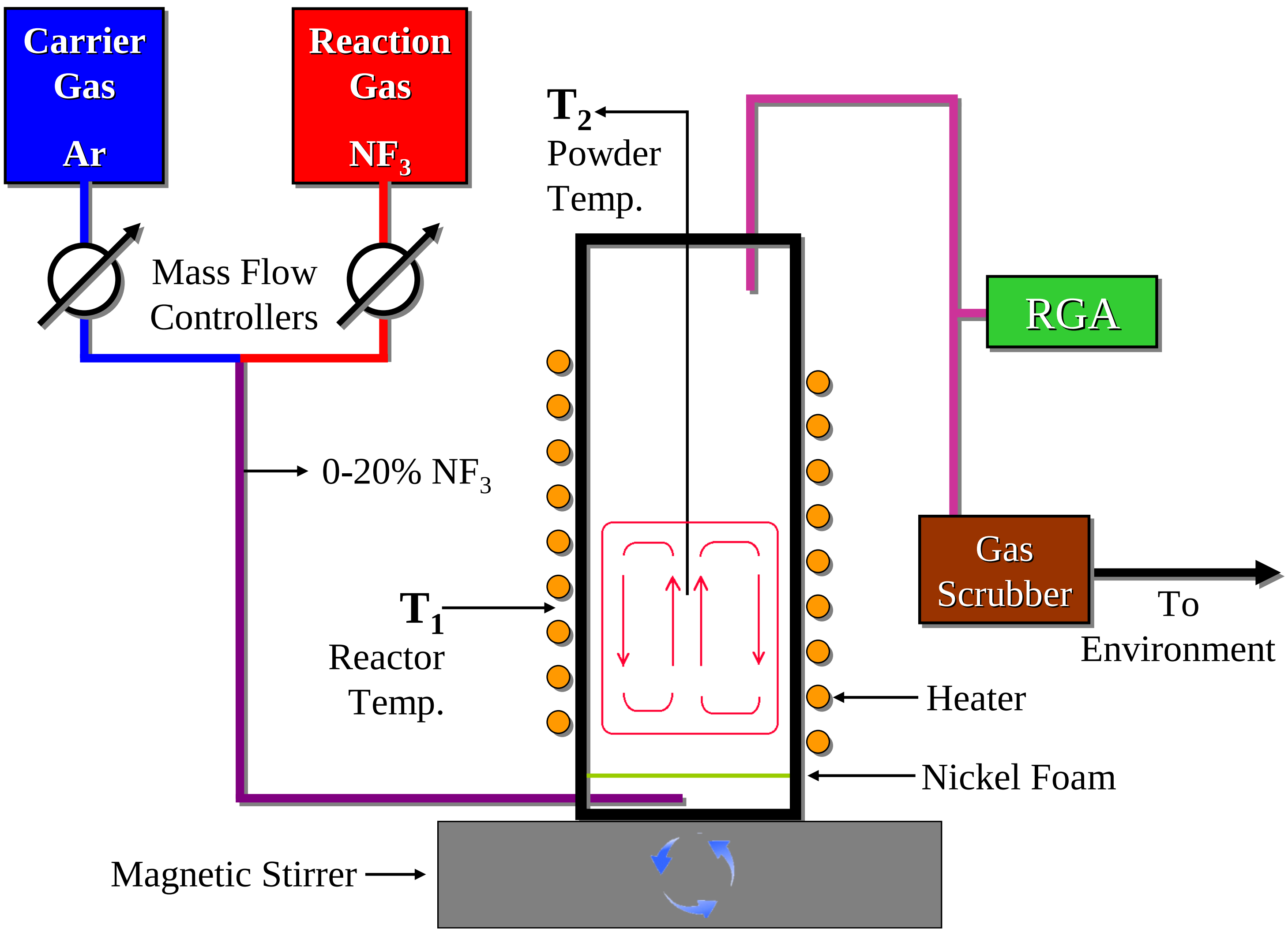

Auger depth profile of passivated flake

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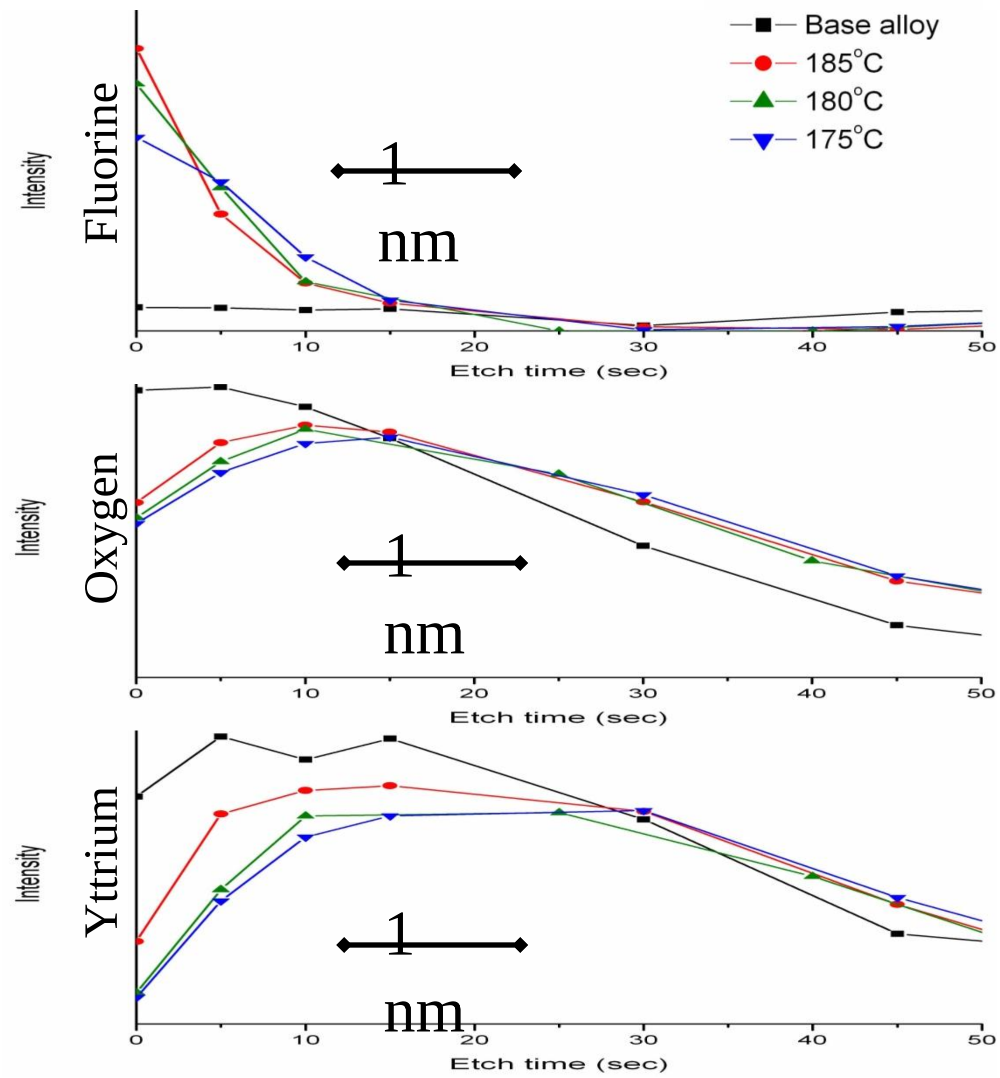
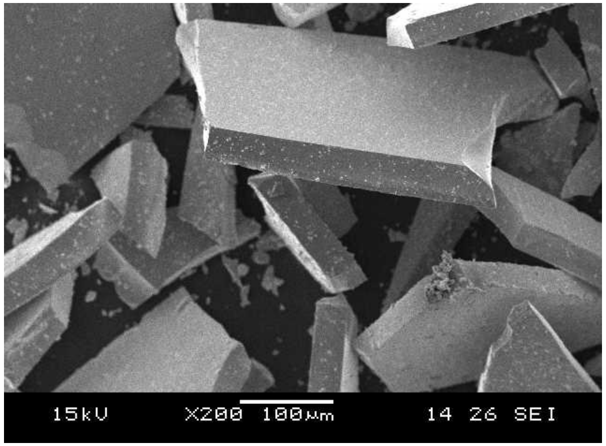


Base alloy MQP-11HTP commercially processed Ames alloy with oxide on surface from 1 year air exposure



Auger depth profile shows effective conversion of oxide surface to fluoride surface with a thickness of ~1nm

XPS Results: Improved Energy Resolution, Area (~mm^2) Sampling

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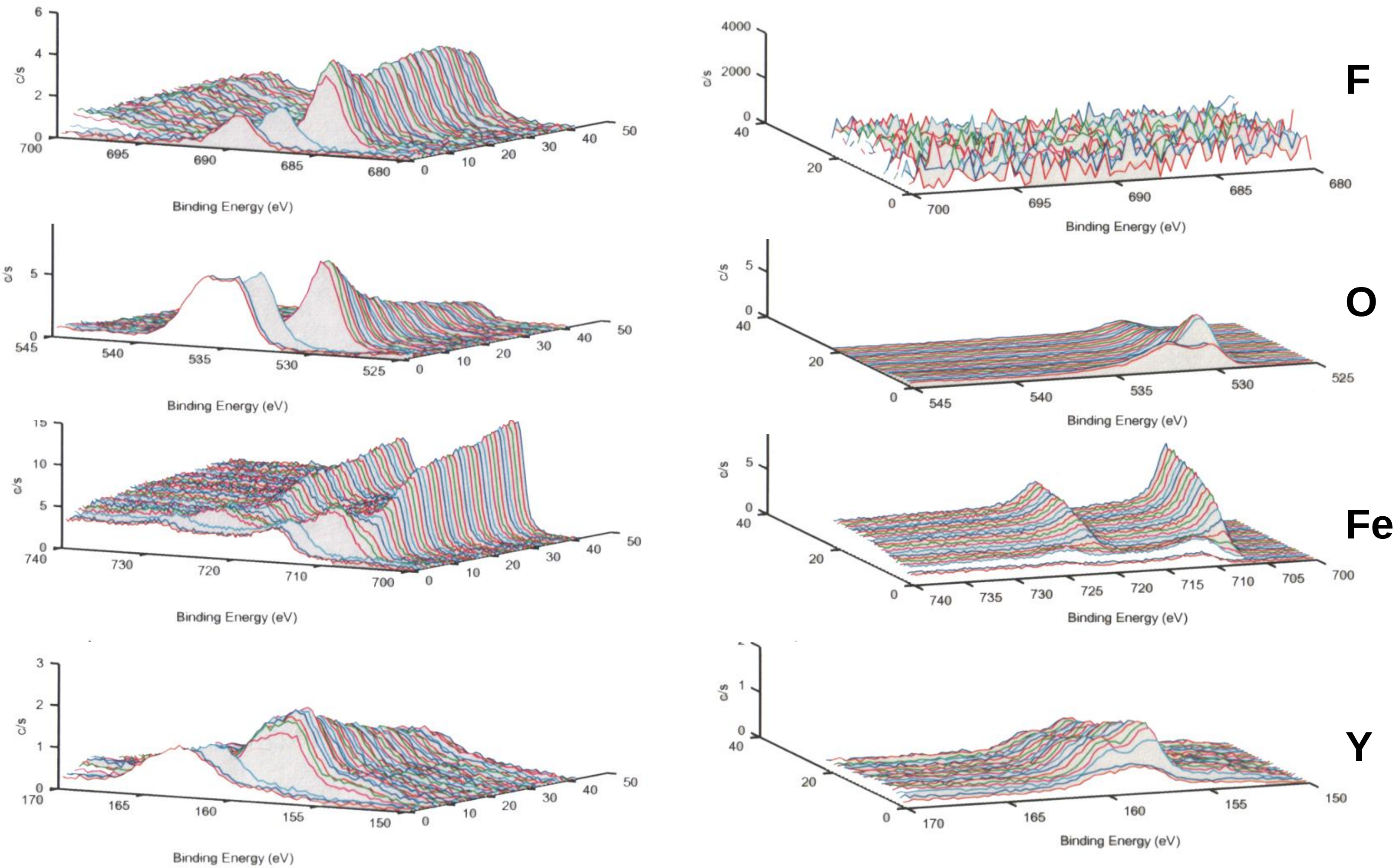
FreedomCAR

Fluoride treated | **Untreated**



Protective Coating of $RE_2Fe_{14}B$ Alloy Powders by Fluoride Treatment

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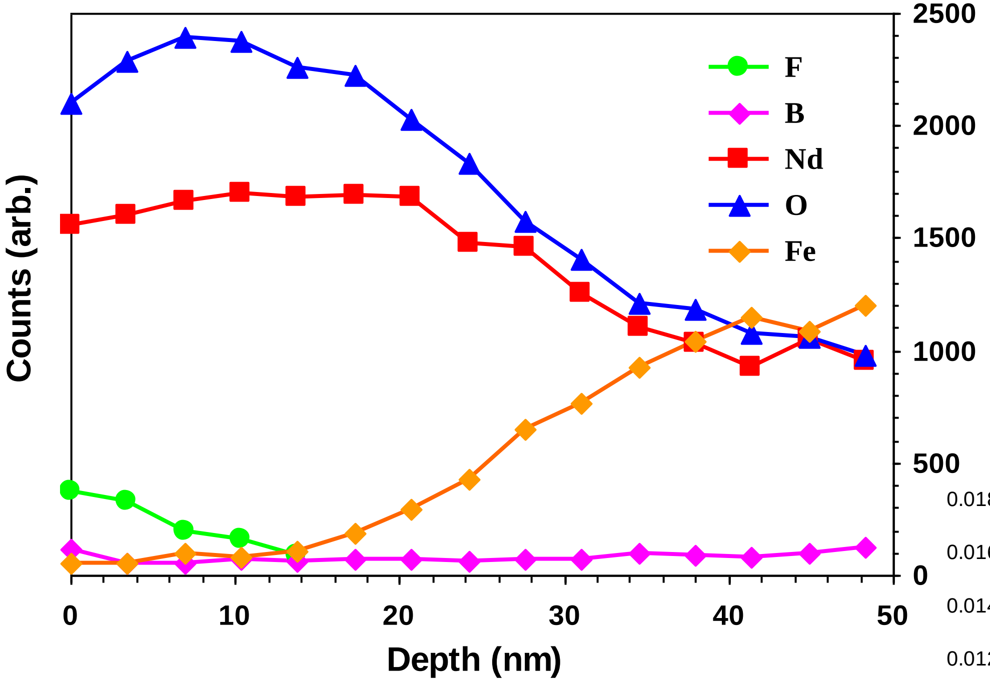
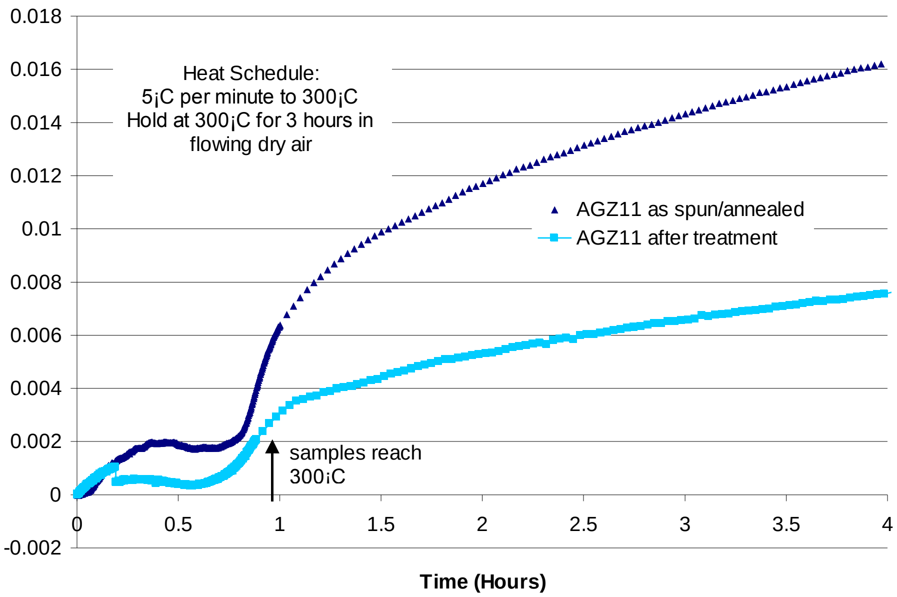
- Auger Depth Profile





- Weight gain when heated in air

Short Term Irreversible Loss Test

Coated Ames Powder versus Commercial Powder

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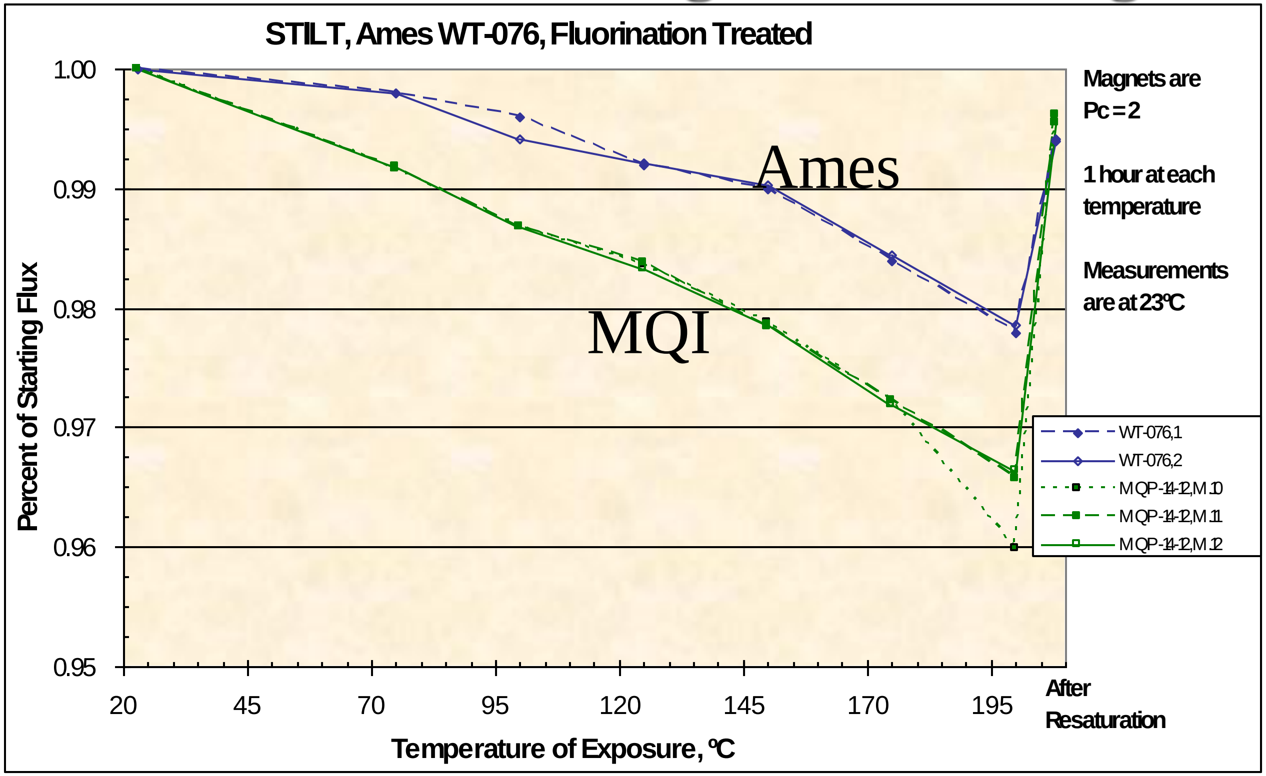
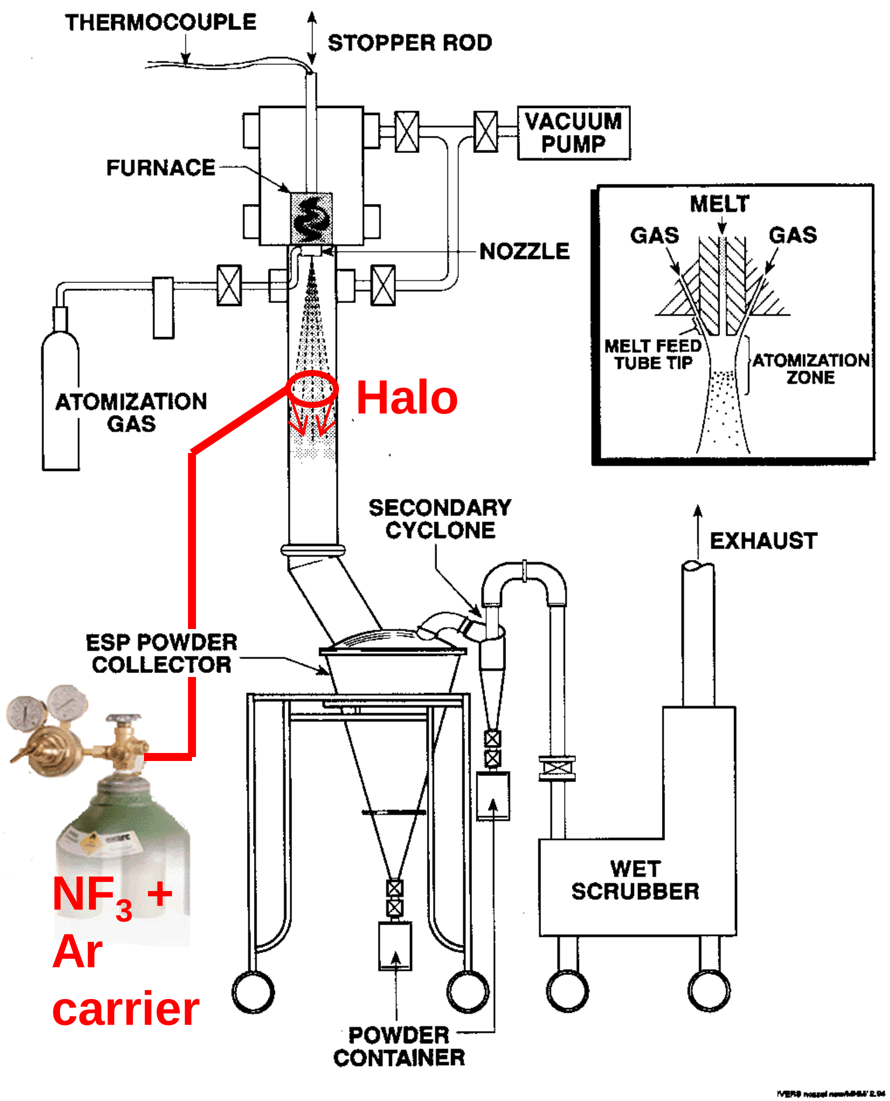
Performed at Arnold Magnetic Technologies



- Results of first generation coating technique on the STILT properties
- Characterization of coating revealed it was highly non-uniform

Gas Atomization with In situ Fluoride Coating (GA-1-66):



- First implementation of in situ protective coating with a reactive gas
    - Nitrogen Trifluoride
- Benefit of this processing route
    - Reduction in post atomization processing costs
    - Increased oxidation resistance
- Process Monitored with use of RGA (below Halo) and Thermocouples (Halo and powder collector)
- Variables that can be controlled:
    - Relative concentrations
    - Flow Rates
    - Temperature zone of injection

In situ surface passivation of gas atomized powders

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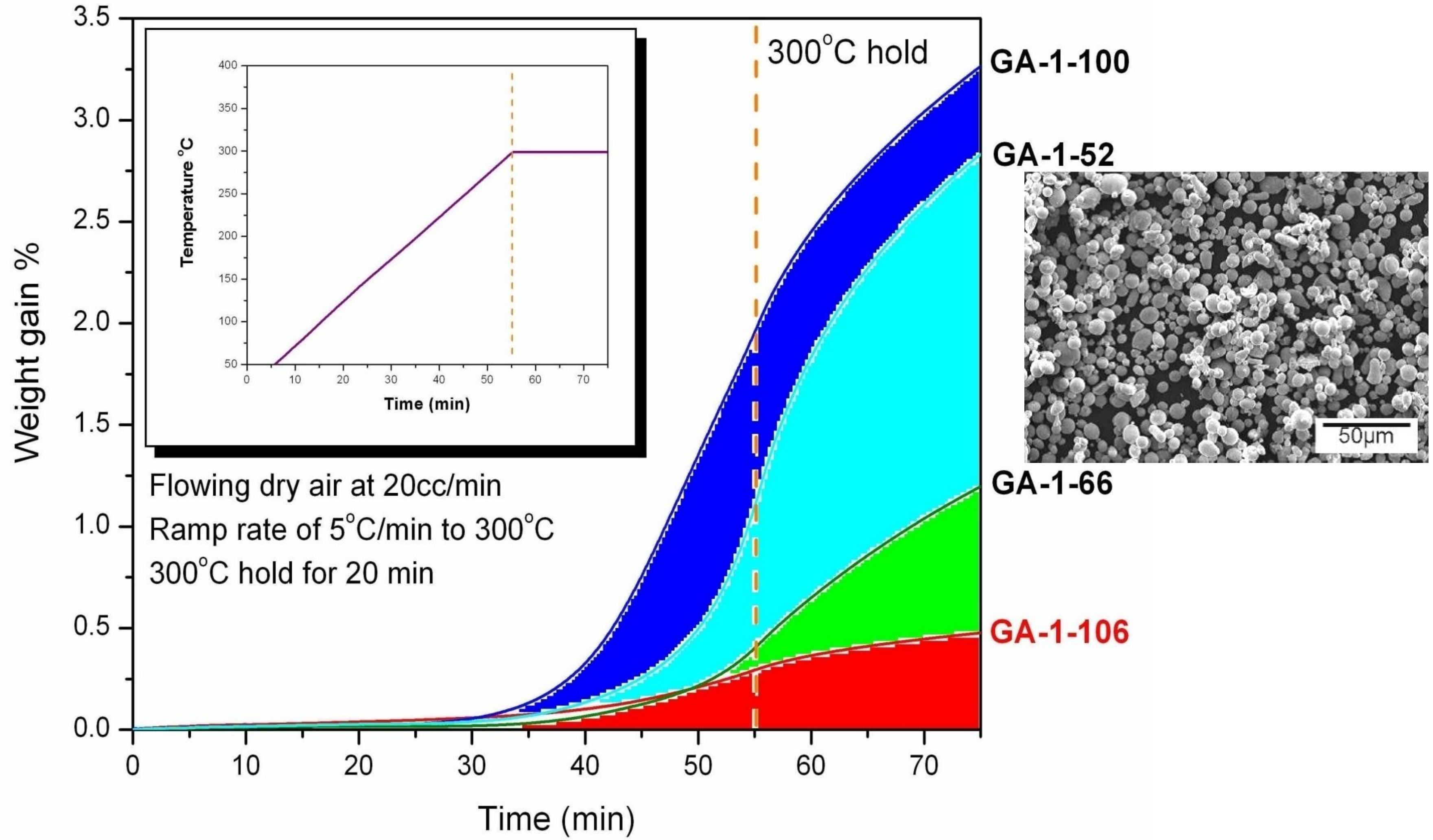

XPS on atomized powder

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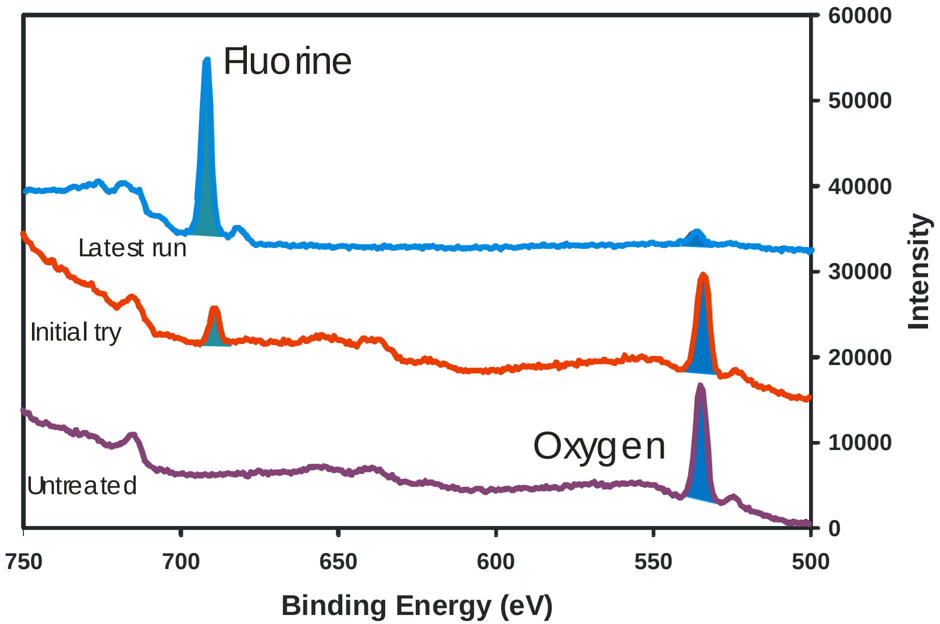
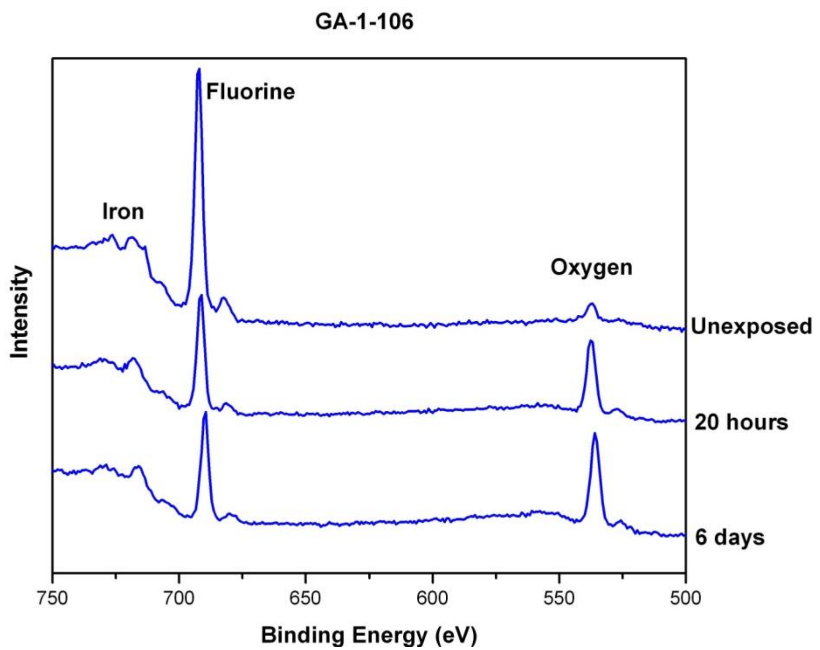


As Atomized

Fluorine peak confirms presence of passivating coating as a result of in situ treatment

Time evolution of oxidation



Oxygen peak height relative to iron peak height after 6 days exposure to air less than the as atomised oxygen peak height without treatment. Oxide layer does not increase after 20 hours

Passivation and Oxidation Protection from Fluorination

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GA-1-52


MINIMUM EXPLOSIBLE CONCENTRATION (MEC) : 140-150g/m^3

Test No.	Concentration (g/m^3)	Pressure (bar)	Rate of Pressure Rise (bar/s)	Ignition
1	100	0.2	59	No
2	110	0.0	0	No
3	150	0.4	75	Yes
4	140	0.2	62	No
5	140	0.3	36	No
6	140	0.2	62	No

Powder without RE fluoride coating probably burned: based on indication of subcritical pressure rise

Oxygen Analysis (LECO)

(~1g at -45µm)	Oxygen Level of unexposed powder
GA-1-52	1800 ppm
GA-1-66	585 ppm


GA-1-66


MINIMUM EXPLOSIBLE CONCENTRATION (MEC) : 120-130g/m^3

Test No.	Concentration (g/m^3)	Pressure (bar)	Rate of Pressure Rise (bar/s)	Ignition
1	150	0.8	180	Yes
2	130	0.5	146	Yes
3	120	0.0	0	No
4	120	0.0	0	No
5	120	0.0	0	No

Powder exploded only at elevated concentrations: presumed from fluoride coating passivation effect