Nitrided Metallic Bipolar Plates

M.P. Brady (project lead)

P. F. Tortorelli

Oak Ridge National Laboratory

Oak Ridge, TN 37831-6115

contact: bradymp@ornl.gov

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Effort Devoted to Scale Up and Demonstration of Thin Stamped Metallic Bipolar Plates

Timeline

- **Start- May 1, 2007**
- **Finish- May 1, 2010**
- **New Project**

Budget

- Total project funding
  - **$4530 K (+ $400 K Match)**
- Funding for FY2007
  - **$1200 K**

Barriers

- **A. Durability**
- **B. Cost**

Targets (2010)

- **resistivity < 10 mohm-cm^2**
- **corrosion < 1 x10-6 A/cm^2**
- **cost < $5/kW**

Team Members

- **ORNL (Lead)**
- **Allegheny Ludlum**
- **Arizona State University**
- **GenCell Corp**
- **LANL**
- **NREL**

Objective: Surface Treatment to Protect Stamped Metallic Bipolar Plates

Overall Goal: ***Demonstrate potential for metallic bipolar plates to meet 5000 h automotive durability goal at cost < $5/kW***

Year 1 Goal:

No significant warping or embrittlement of the stamped plates by the nitriding-amenability of approach established for thin stamped foils

Year 2 Goal:

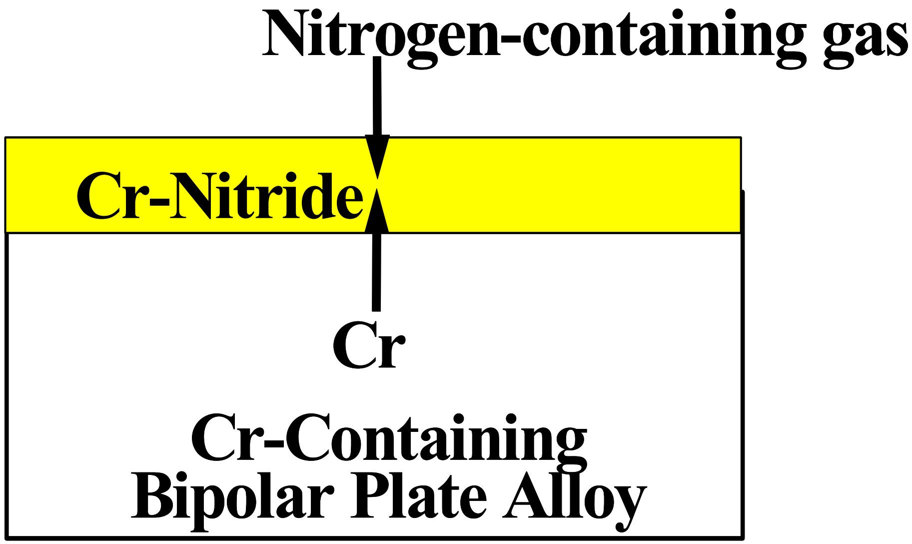
Single-cell fuel cell test performance for ~25 cm^2 stamped and nitrided metallic bipolar plates equivalent to that of graphite (~1000 h, cyclic)

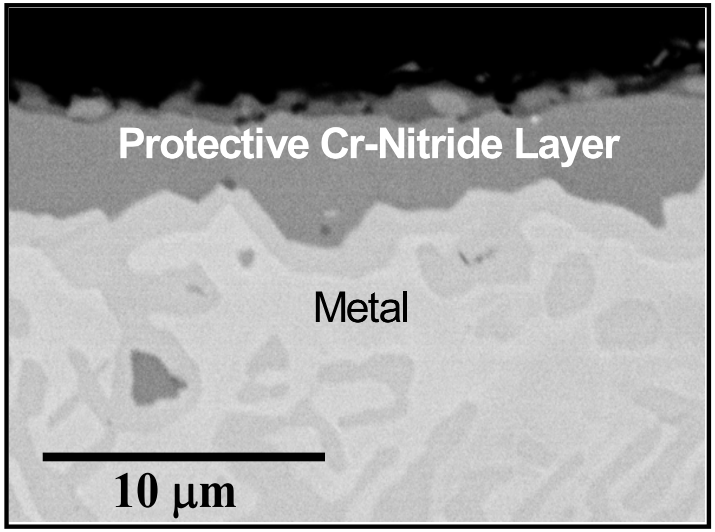
Year 3 Goal:

10 cell stack test of 250 cm^2 stamped and nitrided metallic bipolar plates under automotive drive-cycle conditions (~2000 h)

Potential to manufacture stamped and nitrided metallic bipolar plates at < $5/kW demonstrated

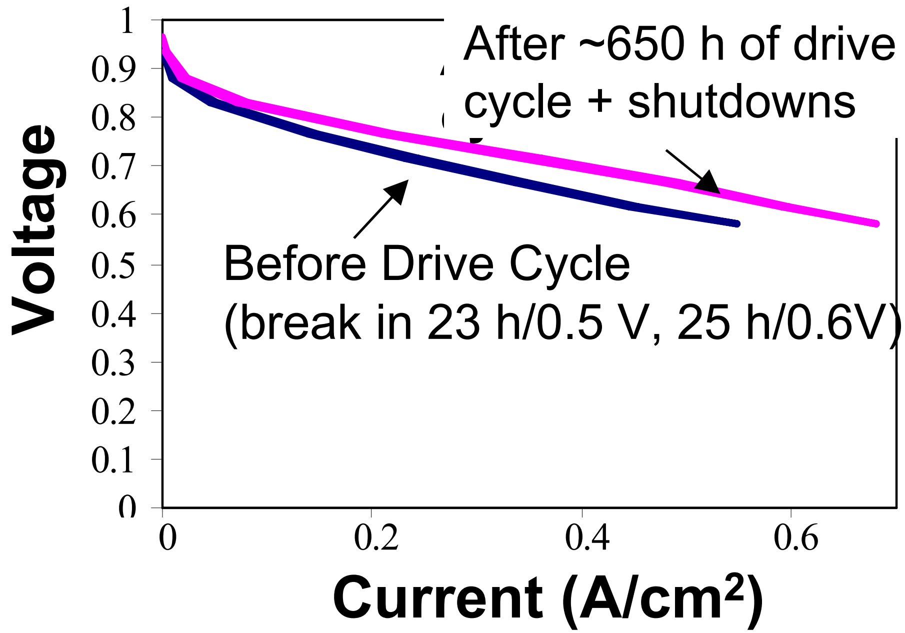
Approach: Thermally Grown Cr-Nitride for Protection





- **Surface conversion, <u>not a deposited coating</u>: High temperature favors reaction of all exposed metal surfaces**
  - -No pin-hole defects (other issues to overcome)
  - -Amenable to complex geometries (flow field grooves)
- **Stamp then nitride: Industrially established and cheap**

Good Single-Cell Drive-Cycle Durability Test Results for Model Nitrided Ni-50Cr Plates



Collaboration with LANL
M. Wilson and F. Garzon

- **1160 h of drive-cycle testing** (after initial 500 h/0.7V/80°C test screening)
  - -0.94V/1 min; 0.60V/30 min; 0.70V/20 min; 0.50V/20 min
  - -additional 24 full shutdowns superimposed

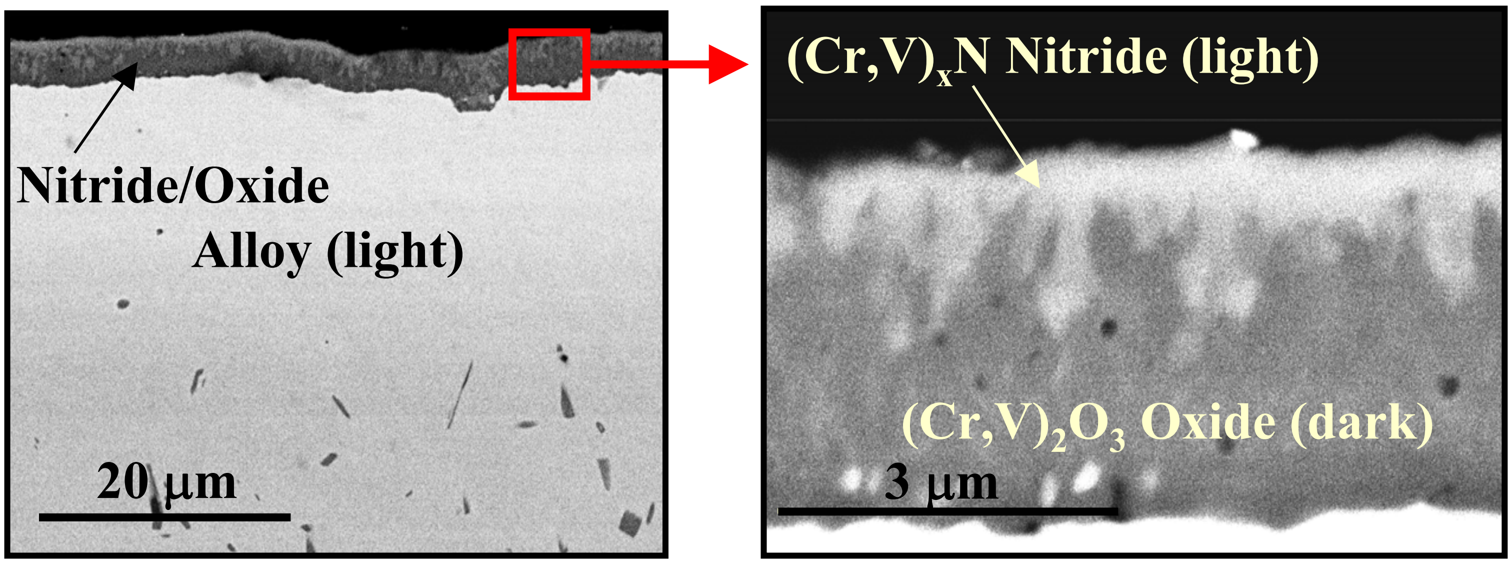
- No performance degradation/No attack of the Cr-nitride
  - -trace level (2x10^{-6} g/cm^2) of Ni detected in MEA, suspect local CrNiN spots

Need Fe-Base Alloys to Meet $5/kW Bipolar Plate Cost Goals

- **Dense Cr-nitride surface formation demonstrated on a model Fe-base alloy, Fe-27Cr-6V wt.%**
  - pre-oxidation key to protective surface nitride formation
  - V segregation into Cr-oxide makes it more readily nitrided
- **Alloy Challenges**
  - Lower Cr and V levels to reduce alloy cost
  - Co-optimize preoxidation/nitridation to segregate Cr, V to surface
  - Down select to ferritic (cheaper) or austenitic (more formable) alloy base

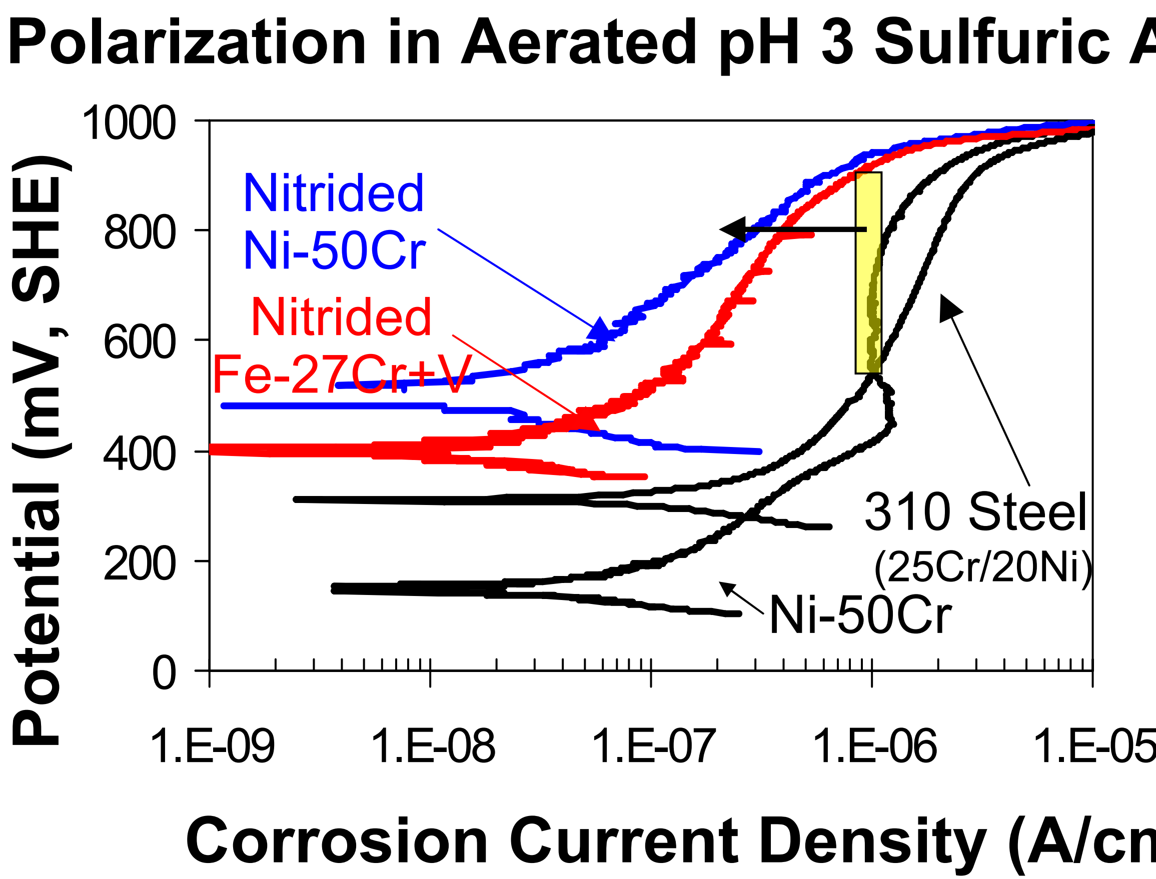
Dense, Continuous Nitride Surface Obtained

SEM Cross-Sections of Preoxidized and Nitrided Fe-27Cr-6V



- Low contact/through-thickness electrical resistance
- Low corrosion current densities under simulated anodic and cathodic conditions

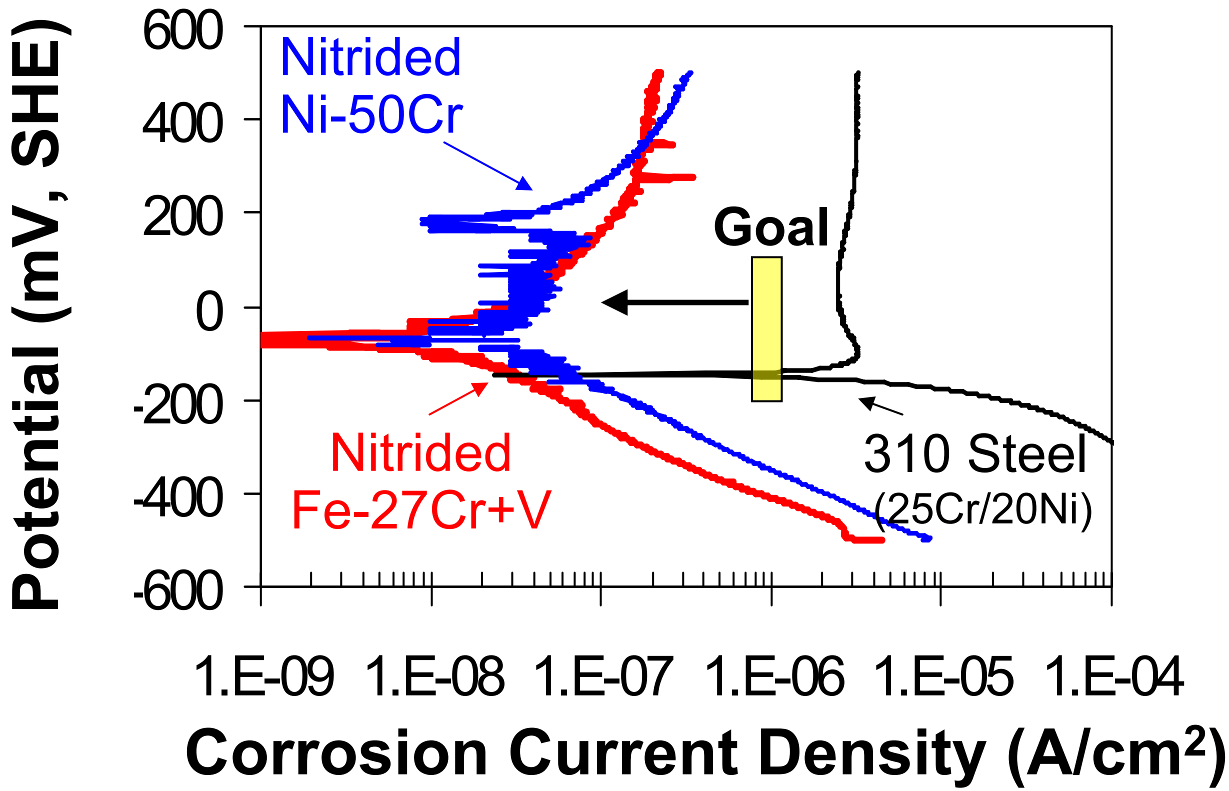
Vanadium Additions to Fe-27Cr Result in Protective Cr-Nitride Surface



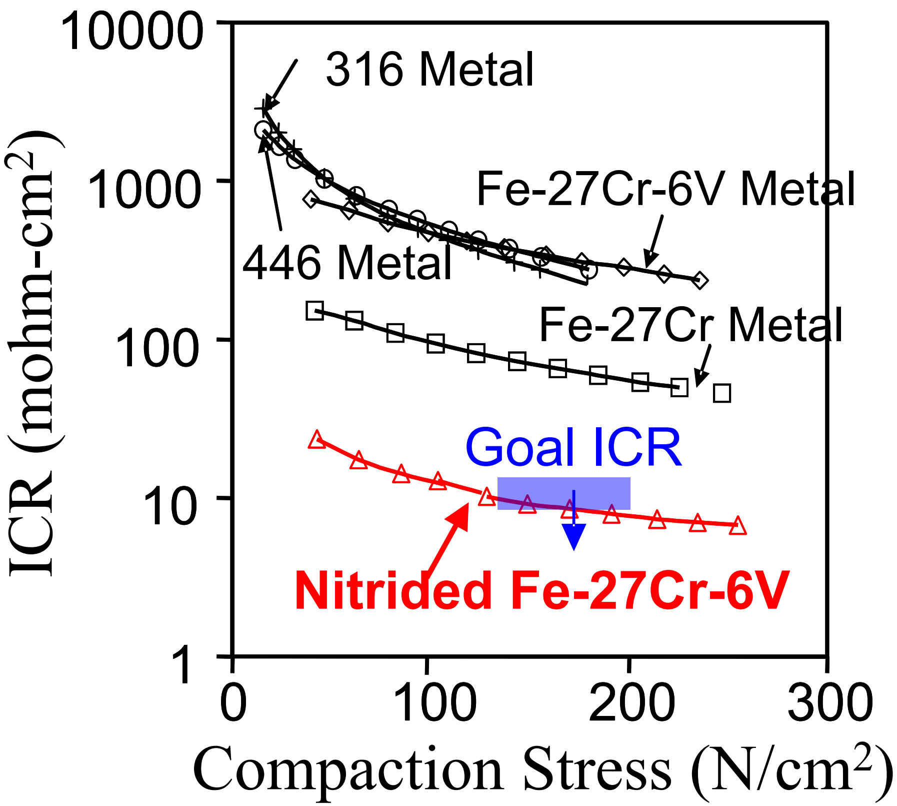
Corrosion resistance comparable to nitrided Ni-50Cr observed for nitrided Fe-27Cr-2V and Fe-27Cr-6V (850-900°C, < 24 h, N_2-4H_2)

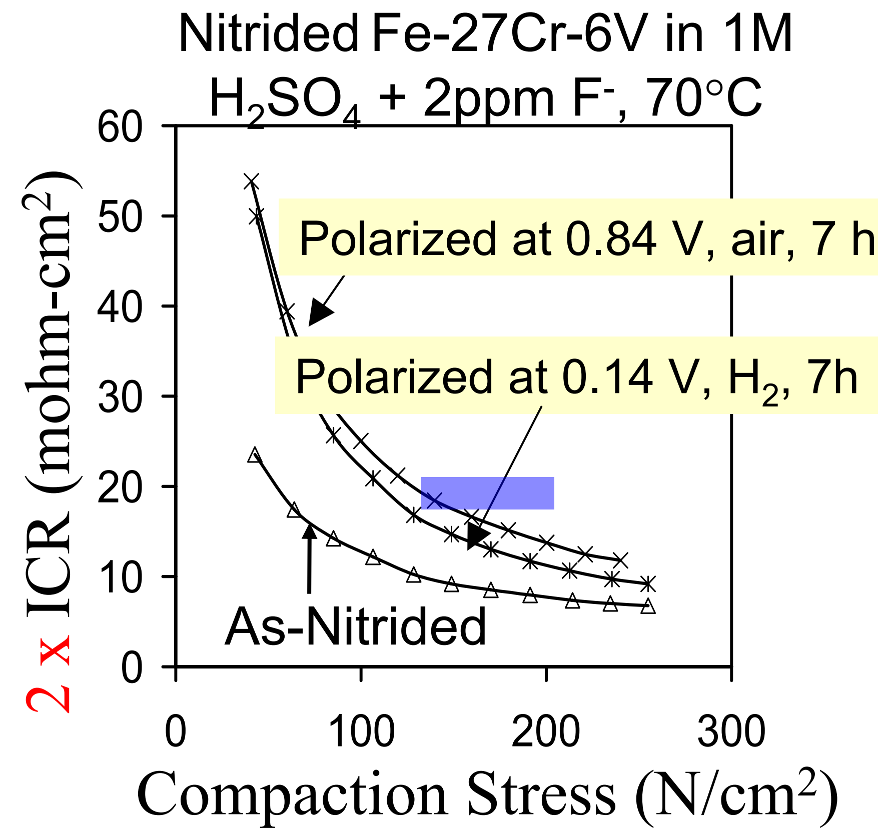
Good Corrosion Resistance Also Observed Under Simulated Anode Conditions

Polarization in Ar-4H_2 Purged pH 3 Sulfuric Acid at 80°C



Nitrided Fe-27Cr-6V Meets and Maintains Contact Resistance Goal

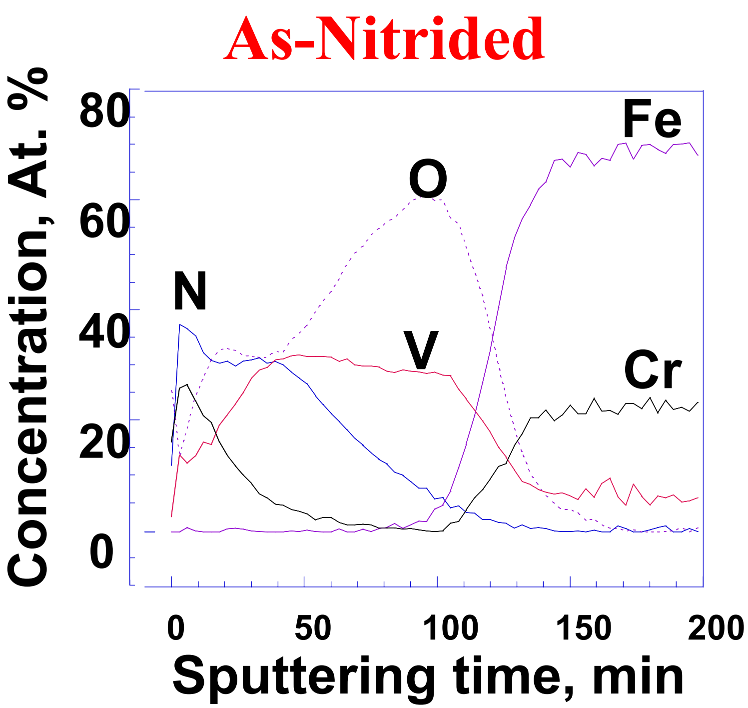


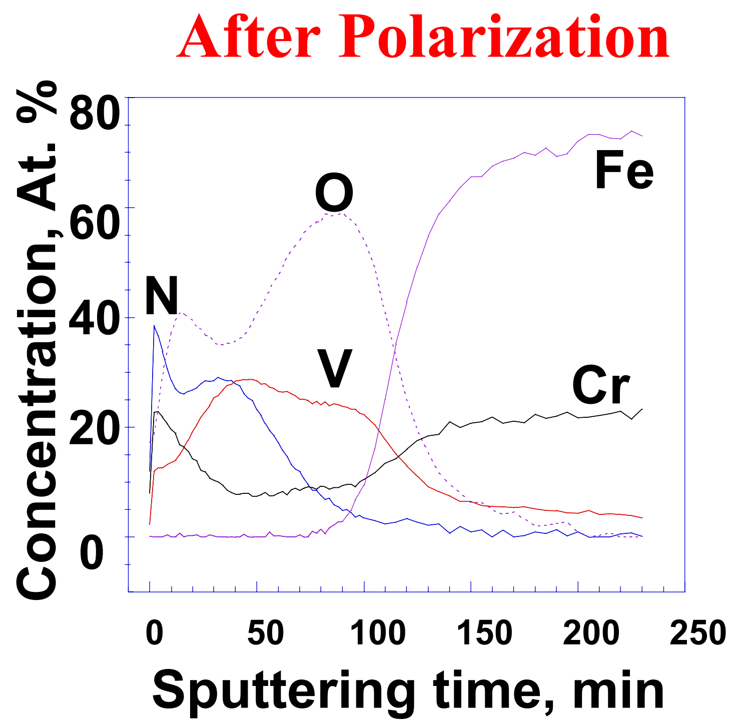


- Nitridation significantly reduces interfacial contact resistance (ICR)
- Slight increase in ICR on polarization-still meets goal
- Untreated stainless steels don't meet ICR goals

Little Effect of Polarization on Surface Chemistry of Nitrided Fe-27Cr-6V

Auger Electron Spectroscopy of Nitrided Fe-27Cr-6V

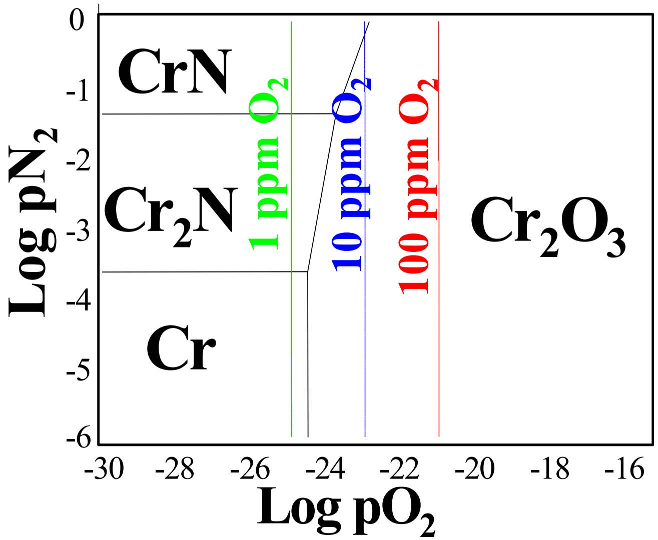


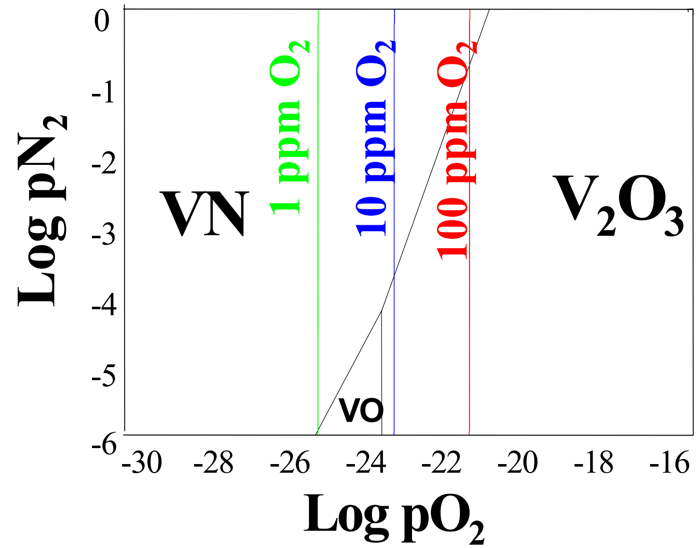


- Polarized 7 h at 0.84 V SHE in 1M H_2SO_4 + 2 ppm F^- air purged at 70 °C (similar results under H_2-purged anodic conditions)
- No Fe detected in nitrided surface

V Additions Destabilize Oxide Relative to Nitride Compared to Cr

900°C Predominance Diagrams





- Order of magnitude greater O_2 impurity stability for VN relative to CrN at 900°C in N_2-4H_2 (100 vs 10 ppm O_2)
- V works because Cr_2O_3-V_2O_3; Cr_2N-V_2N; CrN-VN all mutually soluble
- V_2O_3 and Cr-doped V_2O_3 also conductive – combined with intermixed morphology and N_2-doping yields good ICR values

Teaming and Primary Responsibilities

- Oak Ridge National Lab:
  Alloy design, nitridation optimization, characterization
- National Renewable Energy Lab:
  Corrosion/contact resistance evaluation
- Allegheny Ludlum:
  Alloy foil manufacture
- GenCell Corp:
  Design and stamp bipolar plate flow field features
- Arizona State University:
  Single-cell testing (assisted by Gencell, ORNL)
- Los Alamos National Lab:
  Stack testing and performance assessment, characterization

Stamped Fe-Cr-V Alloys Can Meet $5/kW Transportation Cost Goals

GenCell Corp Cost Estimates for Stamped Bipolar Plates (Nitriding Costs Not Included)

Foil Thick. (in)	Density kg/kW	Bipolar Plate Cost ($/kW) $3/lb Alloy	$5/lb Alloy	$7/lb Alloy
0.002	0.26	$2.31	$3.47	$4.58
0.004	0.38	$3.15	$4.26	$6.57
0.008	0.64	$4.86	$7.69	$10.51

High Cr ferritic alloys $3-7/lb: **viable nitriding costs**

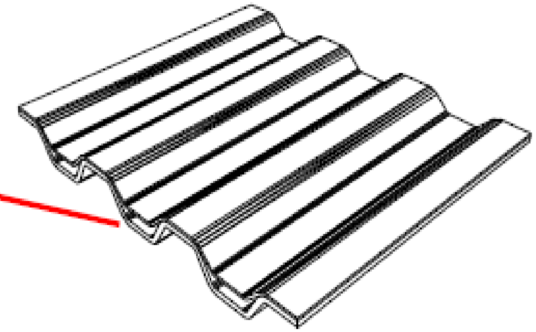
- E-BRITE® (Fe-26Cr-1Mo wt.%): $5-7/lb commercial price for foil
- Alloy 444 (Fe-18Cr-2Mo wt.%): $3-5/lb commercial price for foil
- Above alloys comparable to Fe-Cr-V alloys as Mo and V costs similar

Assumptions: 360 cm² active area plate (494 cm² total area), 2 mil secondary foil for cooling (nested stacking), parallel flow field 0.025” depth, 2010 MEA target power density

GenCell Corp Stamped Bipolar Plate Approach

Internal Chamber (patented)

- "Heat exchanger in each cell"
- Thin wall, high surface area
- From same tooling using nested sheet metal



Above shown for molten carbonate fuel cell bipolar plates, approach currently being extended to PEM and SOFC