Limnia

Plasma Hydride Array System Engineering

(PHASE Technology)

Presented by:

LIMNIA under NDA

Overview

- Project outline
- Background
- New technology array rig
- 1st generation metal-hydrides
- 2nd generation metal-hydrides
- Metal doped glass structures
- Photo-catalysis
- Conclusions

Limnia "PHASE" - Productization Outline

- Develop, engineer and generate highly efficient array system engineering for Limnia (PHASE) technologies.
- Produce the ideal generation of novel materials for the storage of hydrogen using the above technologies.
- Ongoing protection by patent/copyright of technology and license of the new systems to external companies for production and distribution of new materials.

Background

What is ion gas?

- It is ionised gas containing free electrons and ions.
- In Limnia technology, array devices are used to generate the conductive arena. Direct current (DC) is generally used and the arc is stabilized by using magnetic fields, gas injection & RF generators.
- Array processes are characterized by short response time, good process control, high yield, high and consistent product quality, and high production per unit volume.
- The technology meets the demands for more environmentally friendly processes.

Why use this approach?

- Gas-phase synthesis gives the best control over purity, size, shape and crystallinity. Very high chemical purity is practical with gas-phase synthesis whereas it is problematic with many of the other methods. Array heating provides a clean, directional, controllable, high intensity, localised source of contaminant free heat. Other industries have used plasma but it is little-developed for hydrogen.
- In the array zone (operating at up to 20k degrees Kelvin) a range of novel materials can be produced. Limnia‘s approach concentrates on spherical nanometric powders with diameters in the range 15 - 300 nm, with exceptionally high specific surface area/mass ratios, up to >200m^2 g^{-1} .

Advantages over conventional routes

- No contaminants.
- Work under an inert atmosphere (H_2, Ar, N_2 etc.)
- Spherical particles can be formed from solids and facetted particles.
- Fast process cycles, often in minutes, with no need for preheating time.
- Rapid start up and attainment of steady state.
- Compact equipment and small footprint of array rigs.
- Single rig can make range of products.
- Inter-changeablility of services allowing range of rigs to share service infrastructure.

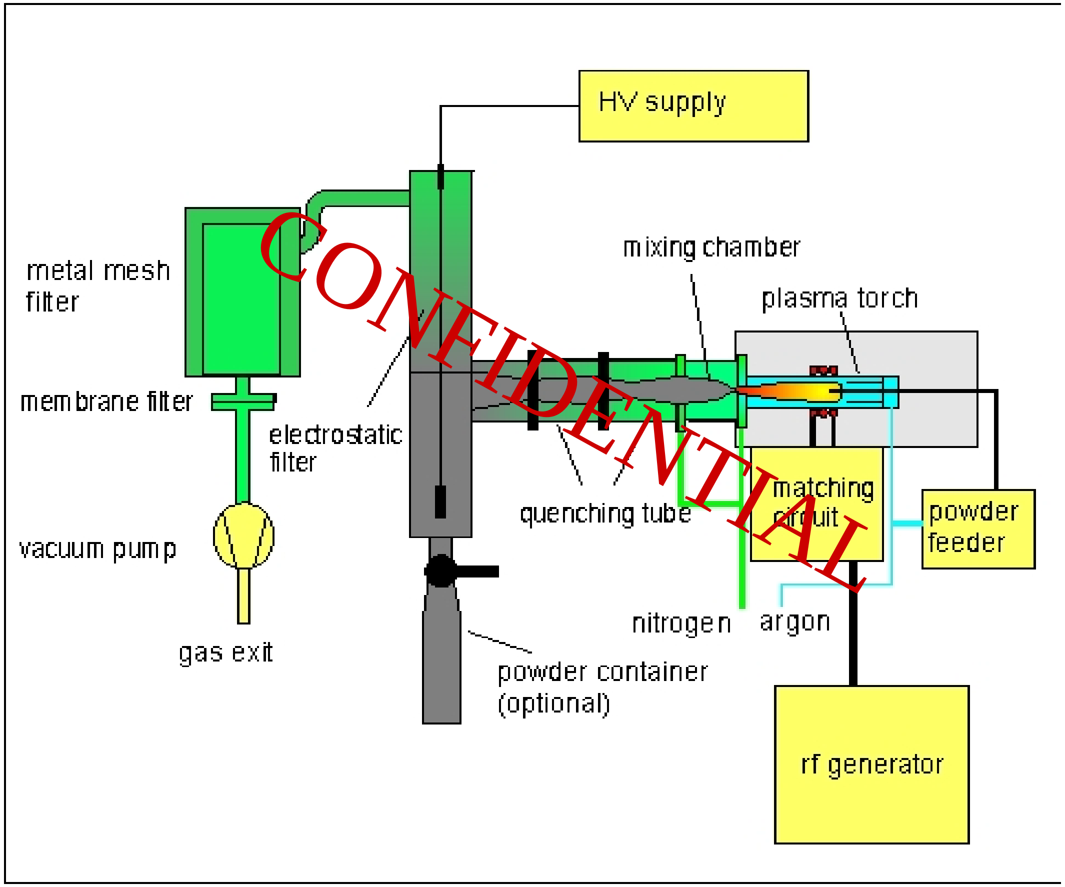
New Technology (PHASE)

Confidential. View under NDA only.

PHASE I Fab Rig

- In order to improve current new alloys and to reduce costs, a fab rig is being constructed in order to optimize alloy candidates.
- Conductive array gun to be used in the process is rated at 100kW. (Approx size = 10cm x 6cm x 2cm) i.e. it is very small/compact.
- 100kW array core torch can produce a 50g batch of material in 30 minutes.
- The diversity of the process allows the screening and production (very fast) of a wide range of novel/new alloys, as media.
- A novel architecture, never before deployed by competitors, with proprietary system subsets unique and exclusive to Limnia.

PHASE I Fab Rig



"*Sanitized*" Simple Boxchart Schematic diagram of PHASE I Fab rig.

PHASE I Processing Components

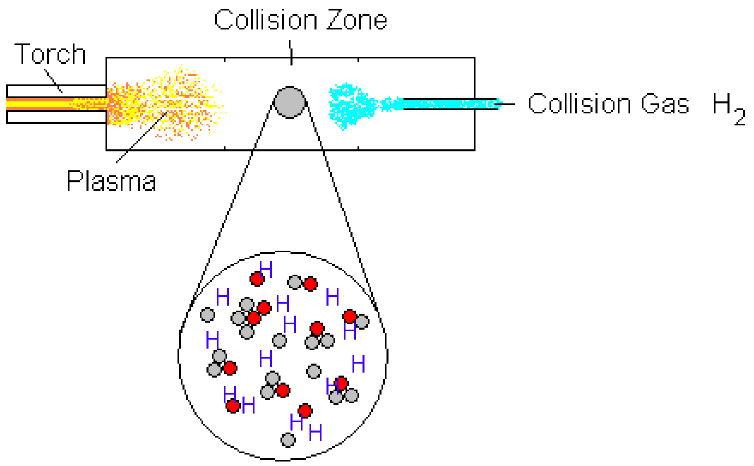
- Feed single materials and mixtures and volatile liquids.
- Material feed rates and method of presentation to the array plume.
- Conductive array torch/electrode type, power input and distribution, spatial configuration and gas flow rate.
- Quench gas identity, rates and timing in the reaction
- Temperature variation and oxidation/reduction processes
- Collection process for end product (directly into Limnia cassettes).

- These variables allow Limnia's array system to be adapted to make a range of materials.

PHASE I Generation Metal Hydrides

PHASE I M-H materials

- Metal powders (Al, Mg, Sn, Ti etc) and liquids ($Fe(CO)_5$) of known high weight percentage ratios with hydrogen are injected into the array.
- Works under inert atmosphere (N_2, Ar, H_2 etc)
- Metals are vaporised into ions, electrons and small clusters.



Schematic of vaporisation and condensation

- On cooling (cryosystem or collision gas), the metal particles undergo condensation/coalescence forming nano-sized crystals (few nm in size).

PHASE I M-H materials

- Target metal species are highly reactive and will “pick-up” collision gas molecules (H_2 preferable), thus forming M-H materials (H_2 also acts to stabilise the metal ready for collection).
- Stoichiometry (tandem feed) is easily controlled, leading to a vast diversity of doped, mixed metal (alloy) metal hydride systems.
- The process of isolation of the materials is <u>very fast</u> (i.e. new materials for characterisation and kinetic testing may be produced every few hours).
- Characterisation of the materials and further testing will be carried out using standard techniques, such as XRD, SEM etc.

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PHASE II Generation Metal Hydrides

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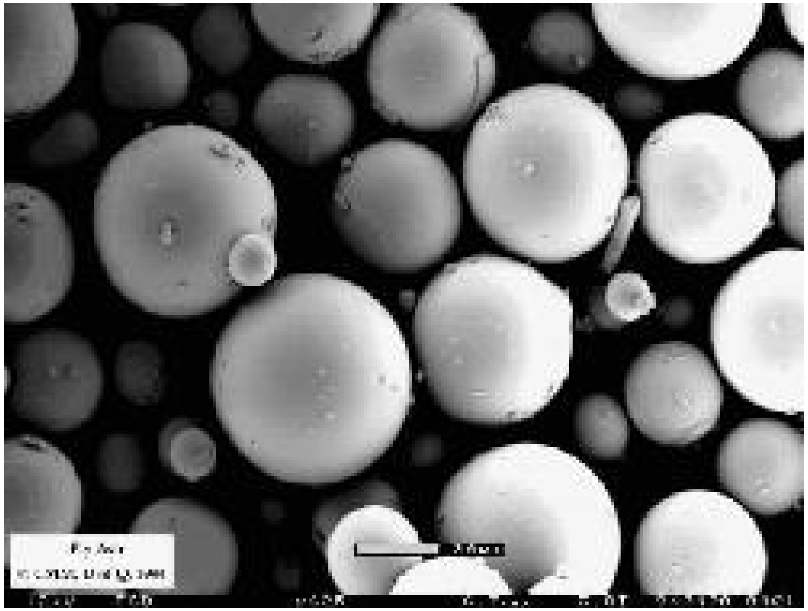
Supported M-H materials

- The supported metal catalysts used widely in technology consist of aggregates (sometimes called clusters of crystallites or particles) of metal of various sizes and shapes dispersed on a support.
- Aggregates (metal catalysts) smaller than about a few nm may be the most important catalytically (hence the use of plasma spraying) because they have a large fraction of metal exposed at the surface and therefore accessible to reactants (hydrogen).
- These very smaller clusters are of most interest structurally, since they resemble molecular species more than bulk metals.

Supported M-H materials

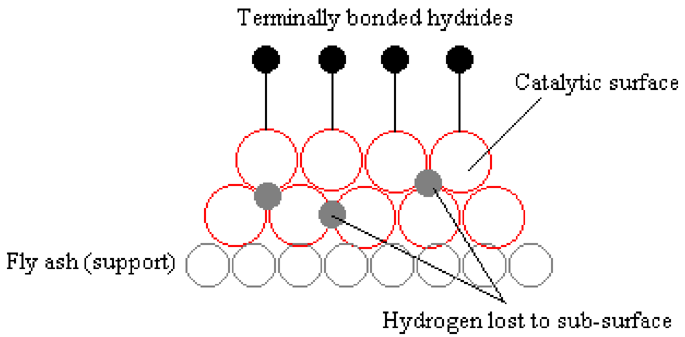
- Direct spraying within the array onto alumina/silica supports.
- Supports introduced with collision/buffer gas.
- Fine layer (few nm of metal) produced on the surface.
- Metal Alloys (mixed metal catalysts).



SEM of Fly Ash (one of many intended supports).

Supported M-H materials

- One of the main problems encountered in hydrogen storage, is the loss of hydrogen to the metal sub-surface. i.e. it requires more energy to desorb it from the metal interior than the surface (higher temperatures).
- Low temperature adsoprtion and desorption.
- High weight percentage of material to hydrogen ratio.



Schematic of a supported catalyst

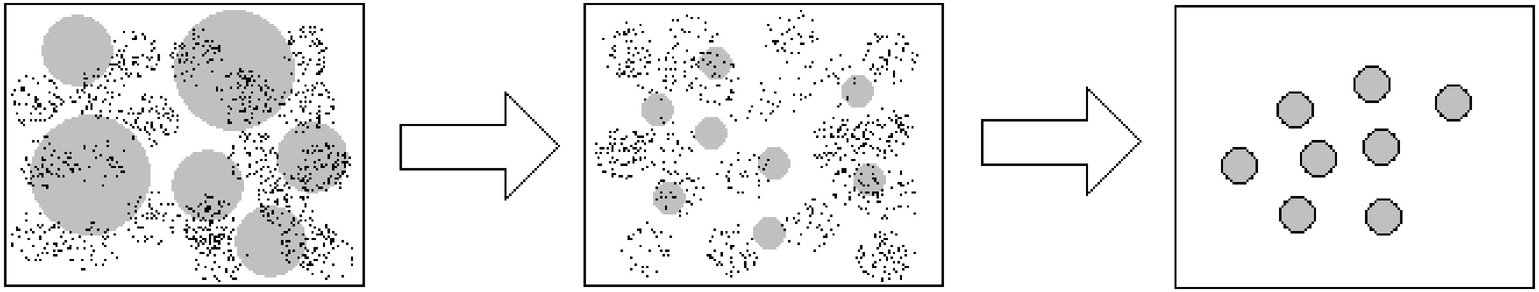
M-H materials

- **Weight Percentage (%)**
- For example the 3d metals and main group elements (Al, Mg, Ti, Si and Zn) are the primary focus of this Limnia compound generation.
- Weight percentages in the order of 7-10 % will be achieved by this method.
- However, 20 - 40% by weight is potentially possible per our tests & analysis. 2 g/cc to 7g/cc are possible with this solution.
- **Storage efficiency (%)**
- The efficiency of these materials will be greater than 90%. The materials are perfect in purity, size, composition, shape and crystallinity.
- No loss of Hydrogen to the system. Therefore should see 100% adsorption/desorption.

Phase III: Metal Doped Glass Microstructures

Metal doped glass spheres

- Coating material + metal will be introduced into the conductive array system.
- Coating of the metallic particles (encapsulation).
- Silica, alumina, diamond, boron nitride etc. are deemed possible candidates for coating the metallic particles.
- Metals/alloys - e.g. Lithium (+10 wt% hydrogen)



Metal powder + support   plasma   Encapsulation

Metal doped glass spheres

- The glassy coating encapsulating the metal particles upon heating and pressure will allow hydrogen to diffuse into the micrsphere on/into the metal.
- The metal will act as a storage medium + giving vital stability (from cracking) to the glass spheres.
- The metal will be protected (inert atmosphere) from gas molecules (e.g. O_2) and H_2O.

PHASE IV Compounds

PHASE IV Metal oxo semiconductors

- Metal powders e.g. (indium, tantalium, nickel etc.) will be introduced into the array in an oxygenated atmosphere (Oxygen Carrier Gas).
- A wide variety of novel mixed metal catalysts can be generated (cf. PHASE I).
- Powders may be supported as in PHASE II. Providing higher surface area of the Catalyst.
- All PHASE I, II, III properties apply to PHASE IV.

Conclusions

- The Limnia PHASE project provides an excellent opportunity for the diverse development and production of Limnia‘s novel technologies and materials.
- The PHASE system will provide inexpensive, environmentally friendly systems and materials.
- All the above PHASE projects are currently Patent Pending under Limnia filings.

Thank you

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