A Monolithic, Self-Powered IC with Fully Integrated Micro-Fuel Cell

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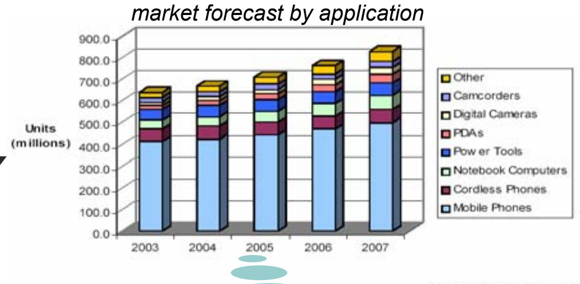
Motivation – Moore's Law

Trends of portable electronics:

- Higher performance
- Lower cost
- Smaller size
- Lighter weight
- Longer operating life

Worldwide OEM power pack market forecast by application



Source: Darnell Group, Inc

A growing demand for portable power

Advancements in power technology have not kept up with Moore's law!

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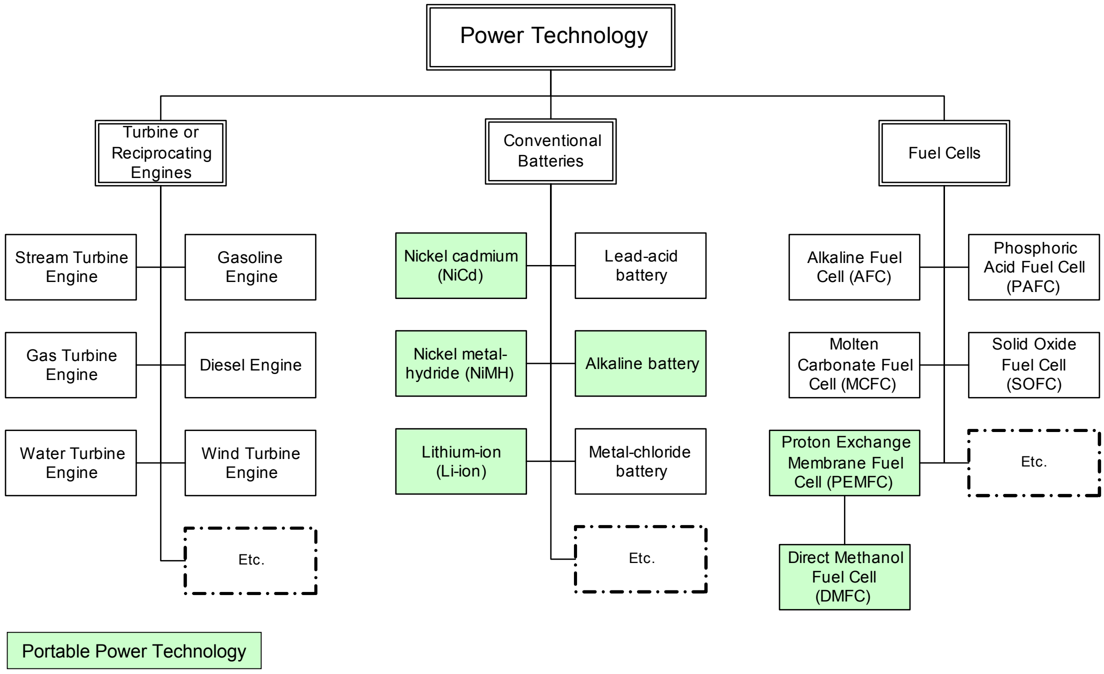
Assortment of Power Technology



Introduction of Fuel Cells

- What is a Fuel Cell?
  - An electrochemical energy conversion device that converts fuel (e.g. hydrogen) and oxidant (e.g. oxygen) into water, producing electricity
- How Fuel Cells work?

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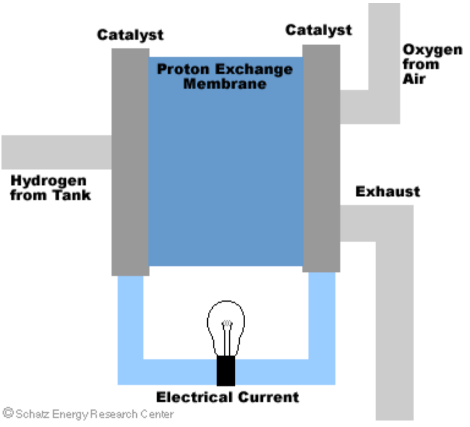
- Applications: Portable power; Auxiliary power; Transportation power; Stationary power
- Classifications: Alkaline-, Phosphoric acid-, Molten carbonate-, Solid oxide-, Proton exchange membrane-fuel cell



Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

** The PEM Fuel Cell Animation courtesy of Schatz Energy Research Center*

Direct Methanol Fuel Cell (DMFC)

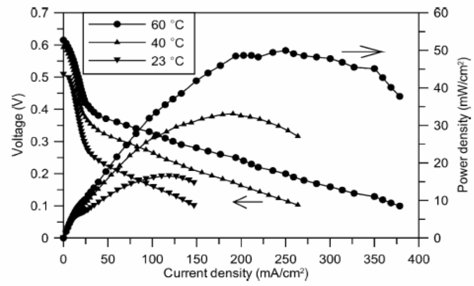
- A variation of PEMFC, suitable for portable electronics
- Advantages:
  - Use methanol instead of hydrogen to eliminate fuel reformer and store fuel easily
  - Potentially high-energy density
  - Environmentally-friendly
  - High efficiency (~40%)
  - Ambient temperature (50-130ºC)
- Disadvantages:
  - Methanol crossover ➔ energy loss
  - High overpotentials ➔ slow response time
  - Low current ratings ➔ only suitable for low power applications
  - Bulky size
  - High cost

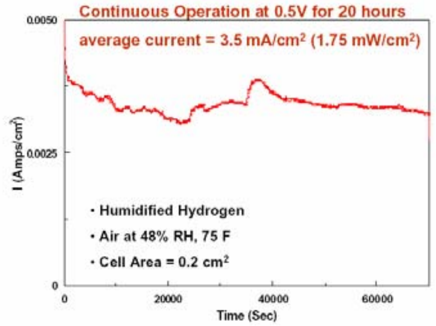
Integrated Micro-Fuel Cell

- Fabricate DMFC into micro-electromechanical systems (MEMS) through silicon CMOS processes
- Low power capability due to available current limitation
- Can be Integrated with IC on the same silicon wafer
- On-board Fuel (methanol) Storage
- Ambient Temperature
- Prof. Kohl and others from Chemical Engineering at Georgia Tech are investigating the integration of micro-fuel cell technology with silicon CMOS
  - Fabrication of microchannel with all-CMOS processes
  - Design and fabrication of integrated fuel reservoir with bi-directional microvalves
  - Design and evaluation of membranes and electrodes

Power Management Challenges

- Self requirements:
  - Accurate voltage reference in the harsh temperature environment; High efficiency; Mode hopping; etc.
- Requirements from load device:
  - Stable supply voltage; Load current sensing; Protection circuitries (over-voltage, over-current, over-temperature), etc.
- Requirements from integrated micro-fuel cell
  - Power curve; Energy drain; Fuel level; Fuel pump control; Thermal regulation; etc.

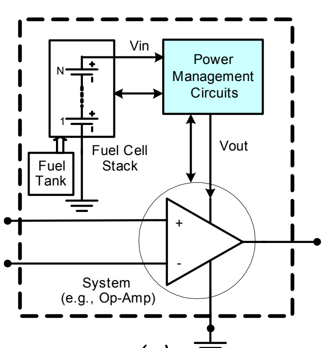




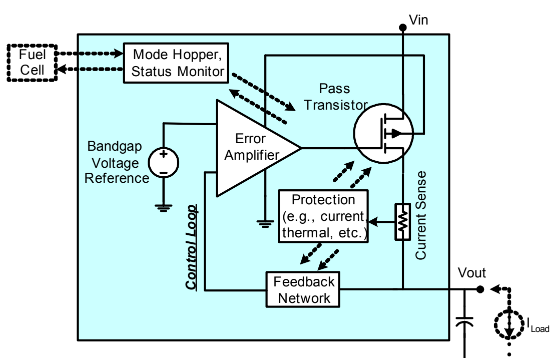
** Images courtesy of CWRU and PSU*

Proposed system diagram

- Monolithic, self-powered IC (Fig. a)
  - A fuel cell stack, power management circuits, a functional system, etc.
- Power management circuits (Fig. b)
  - Bandgap voltage reference, error amplifier, pass transistor, feedback networks, current sensor, mode hopper, fuel cell status monitors



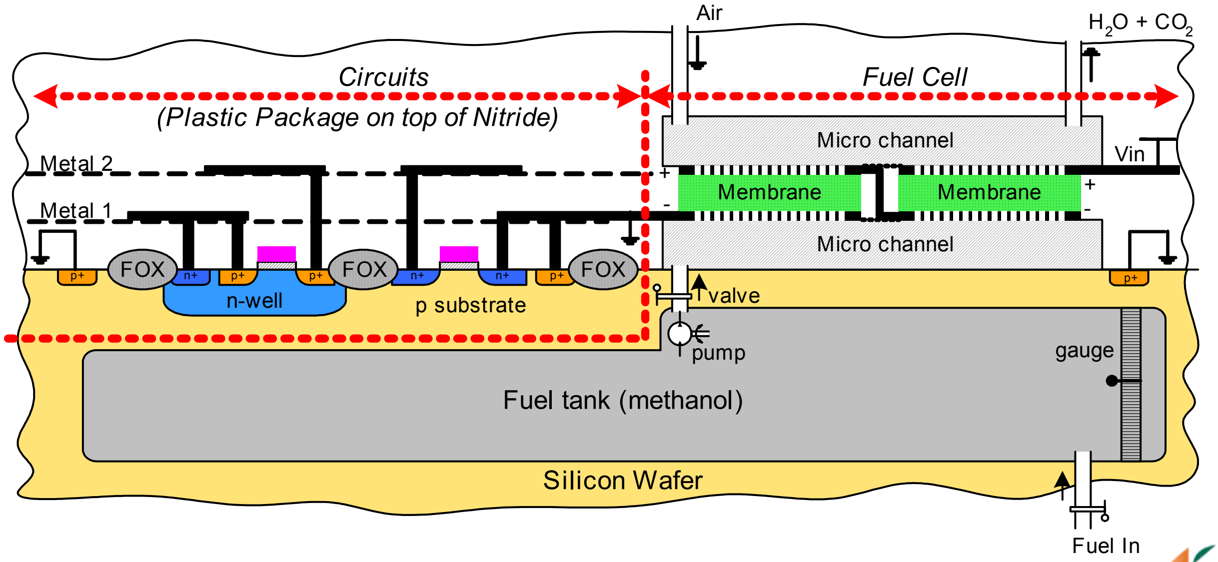
(a)



(b)

Proposed Physical Profile View

- All CMOS processes
- Integrate fuel cell and circuits onto the same silicon wafer



Present status and Goal

- ***Present Status:***
  Infancy (initial investigation and fund match)
- ***Predominance:***
  Expertise in power IC design and access to the on-going research of Prof. Kohl at Georgia Tech (leading expert in integrated micro-fuel cell technology)
- ***Objective:***
  To develop the technology necessary to support and manage integrated fuel cells (e.g., regulation, maintenance, interface, protection, etc.)
- ***Ultimate Goal:***
  To develop a monolithic, self-powered IC, where the battery, its power management circuits, and the system are all integrated onto a single chip.