Powering the Integrated Microsystems

John. D. Evans, Ph.D., MBA
March 7, 2007
San Jose, CA
<table>
<thead>
<tr>
<th>Program</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-D MERFS</td>
<td>Enable dramatic reduction in size (30x) and cost (100x) for MMW systems by demonstrating a new air-core-coax “printed circuit board” technology for MMW.</td>
</tr>
<tr>
<td>Analog Spectral Processors</td>
<td>Enable dramatic decreases in radio size and power by simultaneously trading advances in new radio architectures and new MEMS filters.</td>
</tr>
<tr>
<td>Disruptive Manufacturing Technologies</td>
<td>Exploit opportunities to dramatically decrease manufacturing costs for existing military systems.</td>
</tr>
<tr>
<td>Micro Electric (Space) Propulsion</td>
<td>Demonstrate thrusters with wide Isp dynamic range, enabling spacecraft to flexibly respond to changing national needs.</td>
</tr>
<tr>
<td>Micro Isotope Power Sources</td>
<td>Demonstrate high-energy-density isotope batteries.</td>
</tr>
</tbody>
</table>
The Integrated Microsystem

Sense
- Microbolometer
- RF MMIC
- Micro Gas Analyzer

Process
- Digital Integrated Circuits

Communicate
- All Optical Networks
- Chip Scale Atomic Clock

Actuate
- Micro Electro Mechanical devices

Energize
- Adaptive Photonic Phase-Locked Elements

Microsystems

ALGORITHMS
ARCHITECTURES
ELECTRONICS
MEMS/NEMS
PHOTONICS

Distribution Statement "A" (Approved for Public Release, Distribution Unlimited)
Power vs. Scale for Autonomous Units

- ~200 MegaWatts
  - <0.1% power

- 10-100 kW
  - 2% power

- 1-10 kW
  - 2% power

- 1-10 W
  - 10% power

- W - nW
  - >50% power

Increased projection of U.S. Interests and Capability
Power Density vs. Size

We have yet to effectively scale power systems to small size.
Two approaches

Exploit scaling laws to use less power

Many system-specific opportunities

Really hard

Scale macro power systems
Use Less Power

**Analog Spectral Processors**
Dramatic decrease in radio power by off-loading RF signal processing to passive MEMS filter arrays.

**Chip Scale Atomic Clock**
300X reduction in power consumption (from 10 W to <30 mW) for atomic clocks through system miniaturization.

**Energy Starved Electronics**
Demonstrate 100X improvement in energy per operation over conventional electronics through sub threshold operation.

**Micro-Gas Analyzers**
10,000x decrease in power required per analysis through system miniaturization.

**Super High Efficiency Diode Sources**
80% electrical-to-optical efficiency from semiconductor diode laser bars (880nm to 980nm)

**Micro Electric (Space) Propulsion**
Doubling of electrical efficiency for electric propulsion systems through miniaturization.
Scale Macro Power Systems

Micro Isotope Power Sources
Small power sources based on energy conversion from isotopes.

Micro Power Generation
Micro-scale power generation from hydrocarbon fuel

Energy Density (mWh/g)

Power Density (mW/g)

Time

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited), DARPA Case 8724, 3/2/2007
Micro Isotope Power Sources

Area-based Approaches (beta, alpha)
- Isotope $\alpha$ / $\beta$ source
- Particle $\rightarrow$ electrical converter

Volumetric Approaches
- E.g. Sandia Thermo-Photo Voltaic

Power
- 35 $\mu$W
- 35 mW
- 35 W

Device Lifetime
- 2 mo.
- 2 yr.
- 20 yr.

Anti-Tamper
CSAC, Navigation, Tracking, Logistics tracking/monitoring
Sensors
Soldier Power

Distribution Statement "A" (Approved for Public Release, Distribution Unlimited), DARPA Case 8724, 3/2/2007
Many attempts….

…most have run into significant technical challenges as they move to micro-scale.
Some challenges

- As you miniaturize, surface-area-to-volume increases. Drives inefficiencies…
  - Thermal losses (quenching)
  - Friction (bearings)
  - Viscous losses in liquid flow
- Poor mixing on micro-scale
  - Low Reynolds numbers poses limits on use of turbulence
  - Diffusion insufficient
  - Chaotic mixing limited by 2-D nature of micro-fabricated systems.
Microfluidics Limited by Geometric & Materials Constraints

Valves (pumps, regulators, etc.) typically require
- Precision fabrication in at least two orthogonal planes
- Multiple material properties for structure, seal, etc.

J. Evans, Quadra-Pole mixer

J. Evans, Spring valves

J. Evans, ‘BSaC’ Valve
Goal:
Demonstrate an affordable, high performance 3-D "Printed Circuit Board" technology for RF/MMW based upon air-core Recta-coax.

Technical Challenges

Phase I:
• Precision 3-D fabrication using new material system that utilizes air (sacrificial material), copper, and structural polymer.
• Demonstration of new sacrificial high-aspect-ratio photo resist.
• Demonstration of new metal/polymer/copper CMP process.

Phase II:
• Double number of lithographic layers (5 → 9), thereby enable crossovers and doubling RF performance.
• Balance layer adhesion vs. CMP shear stress.
• Improve fabrication yield.
Images of 3-D MERFS Structures
(5 lithographic layers, 3 Material)

“Launch” De-imbedding Test Structures

Attenuation Test Structure

Isolation test structures

Cavity Resonator

Hybrid Coupler

6-Inch 3-D MERFS Wafer on RF Probe Station

SEMs Copyright © Rohm & Haas
Maybe its time for a new push…

USC Swiss-Roll counter-flow heat exchanger

MIT Micro-Turbine

Berkeley Micro-Wankel

CalTech Micro-Solid Oxide Fuel Cell

New Polystrata™ Fabrication Technology Enables complex 3-D MEMS Geometries

Critical mass of new ideas?

Who’s the next Power PM?
Maybe it’s you…

You?

Your name here
Powering the Integrated Microsystem

John. D. Evans, Ph.D., MBA
March 7, 2007
San Jose, CA