“Electroactive Polymer Artificial Muscle – A Polymer Based Generator?”

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Who We Are

- **AMI History**
  - Founded as an independent company in 2003
  - Spun-out of SRI to commercialize electroactive polymer artificial muscles (EPAM™)
  - $25M of funded development over ~ ten years
  - Located in Sunnyvale, CA
  - ~ 50 Employees
What We Do

- New class of OEM **smartMOVE™** actuators, generators, and sensors for the consumer, medical, and industrial markets.
- This proprietary **smartMOVE™** (EPAM) technology meets the growing *market needs* for:
  - Reduced power consumption
  - Higher mobility
  - Improved safety and reliability
  - Quieter operation
  - Fewer mechanics
  - Lower cost

*EPAM will do to actuators what semiconductors did to vacuum tubes*
Development Milestones

- **1960’s** – Japanese researchers identify first electro-active polymers (EAP), based on ionic gels, considered a scientific curiosity
- **1990’s** – DARPA funds $10M’s for advanced actuator research, leads to piezo, shaped memory alloy and EAP development
  - SRI researchers, led by Ron Pelrine, develop dielectric elastomer Electroactive Polymer Artificial Muscle (EPAM) using commonly available silicone and acrylic polymers, solving many of the technical and cost issues associated with wet, expensive materials used in ionic EAPs
- **2001** – 1st of more than 30 EPAM patents issued
- **2003** – Artificial Muscle Inc. founded by 3 SRI researchers to commercialize EPAM
- **2004** – AMI Product development initiated, EPAM development kits shipped to more than 20 companies
- **2005-07** – AMI product development achievements:
  - High-performance silicone material developed
  - Diaphragm Actuator product platform applicable to many product opportunities introduced
  - Low-cost drive electronics engineered
  - High-volume electrode printing process and inks developed
  - Announced 1st product for camera lens A/F actuator & trials begin with leading camera module suppliers, OEMs and handset mfg’s.
  - Secondary products developed: micro pump for medical markets; dynamic valve for industrial markets;
  - AMI enters into manufacturing agreement to supply production needs
- **2008** – 1st Product launch, Mfg. scale-up, product revenues
An EPAM device is composed of:
- A parallel plate capacitor comprised of:
  - a thin film elastomeric dielectric that has been pre-strained
  - Conductive conformable electrodes

The device is activated by:
- Applying an electrical charge to the electrode that creates an electrical field in the dielectric
- The charged dielectric thins due to Maxwell Force causing an increase in the film’s area
- The resultant increase in Cartesian area is captured and converted to Z-Axis motion using AMI’s patented design
AMI’s EPAM technology relies on the ability of our device to perform work in the form of “stroke”. Stroke is governed by the following approximation for the film used:

\[
\text{Stroke} \approx \frac{\varepsilon_0 \times \varepsilon_s \times E^2}{Y},
\]

Where:
- \(\varepsilon_0\) = Permittivity of air
- \(\varepsilon_s\) = Dielectric Constant
- \(E\) = Electric field or operating voltage/thickness
- \(Y\) = Young’s Modulus
How it works… think of a flexible capacitor
Key Benefits of smartMOVE™

- The new smartMOVE technology platform enables a new class of products which are:
  - Energy efficient
  - Inexpensive
  - Lightweight
  - Small and quiet

- These new products:
  - Generate little heat
  - Produce no magnetic fields
  - Have a broad frequency response
  - Provide direct drive

smartMOVE technology will replace traditional electromechanical motion
Universal Muscle Actuator (UMA)
- Addresses 75% of current applications
- Patented Double Diaphragm Platform

Scalable performance parameters
Scalable physical size (mini to macro)
Simple manufacturing process
- 2-D flat film manufacturing process
- Multiple configurations can be easily “printed”

Addresses 75% of current applications
Technology is Scalable and Configurable

- Extremely Flexible Design
- Displacement and stroke scale with size
- Force scales linearly with number of layers
- Patterned electrodes enables complex movement

Flexible, Scalable and Configurable
The Energy Production Cycle

1. Stretch the EPAM Film
2. Apply bias voltage
3. Relax EPAM film and remove voltage @ constant field
4. Continue relaxing EPAM film and remove voltage @ decreasing field

Electric Field (E^2) vs. Strain
How it works...

\[ C_i = \varepsilon_o \times \varepsilon_r \times \frac{A_i}{d_i} = 400nF \]

\[ C_s = \varepsilon_o \times \varepsilon_r \times \frac{A_s}{d_s} = 1600nF \]

\[ C_s \times V_s = Q_s = Q_i = C_i \times V_i \]

\[ A_V = \frac{V_i}{V_s} = \frac{C_s}{C_i} \]

\[ A_E = \frac{0.5 \times C_i \times V_i^2}{0.5 \times C_s \times V_s^2} = \frac{C_i \times V_i \times V_i}{C_s \times V_s \times V_s} = \frac{V_i}{V_s} \]
Simulation Results of EPAM Generator
License – Wave Power Generation

- **Market Opportunity**
  - Wave power is a viable alternative energy source in many regions
  - 1st application is self-powered wave power buoy for harbor, port, coastal safety – lights and beacons
  - Will also be used for Seawall generation

- **AMI Advantages**
  - Scalable, distributable energy
  - EPAM is ideal impedance match for wave power and other naturally occurring frequencies
  - EPAM generators are best suited for applications that have very high forces and very low velocities
  - EPAM generators ideally suited for applications using high DC voltages (2-10 kVdc) for distribution
Many Other Power Generation Ideas...

Fluttering wind generators can be located as discrete devices or strung from flexible wires across large areas for wind energy generation in urban or rural settings (across a valley or on the top of tall buildings).

Floats provide extension motion by riding on waves.

Dielectric elastomer located within stretchable tether.

Energy storage and accumulation station.

Diaphragm Generators
Summary

- Currently, AMI is starting to commercialize EPAM based actuators
- AMI’s goal is to concentrate on market needs for improved actuators
- AMI has the strongest EPAM IP portfolio
- EPAM devices utilize Maxwell Force Cartesian Plane area growth and AMI’s patented design to create Z-axis actuation
- The technology enables a new class of products with high energy density
- EPAM is viable for energy generation
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