

Environmental Logging Microsystem (ELM) For Downhole Applications

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Summary: Downhole environmental monitoring can provide significant benefits to the petroleum industry. Knowledge of downhole geophysical conditions, such as temperature, pressure, and chemical concentrations in oil wells, hydraulic fractures, and reservoirs, can guide decisions governing operational efficiency and safety in exploration and production. Current data collection methods, including well logging, crosswell imaging, and seismic studies, provide aggregate information that could be supplemented by sensing microsystems with data logging capabilities.

This work presents an environmental logging microsystem (ELM) for downhole monitoring applications. The ELM combines a micromachined pressure sensor and off-the-shelf electronic and battery components. Each ELM includes a microcontroller unit (MCU) for temperature measurement and system control, 1 or 2 pressure sensors for pressure measurement, 3 V lithium coin cell rechargeable battery, a charging circuit for optical charging of the battery, and two LEDs for optical communication. The ELM components were integrated on a flexible printed circuit board (PCB) and folded into a stack of $7.2 \times 6.6 \times 6.5 \text{ mm}^3$. The folded systems were encapsulated in steel packages filled with silicone or proprietary epoxy for the targeted high temperature, high pressure, and corrosive environments. Encapsulated systems were successfully tested at temperatures up to 150°C and pressure up to 10,000 psi, in environments of American Petroleum Institute (API) standard brine, Isopar[®]-L, fracking gel, silicone oil, and a proprietary mud solution. Systems were also tested in a brine well at depths up to 1235 m (limited by available cable length), with temperatures up to 70°C and pressure up to 1800 psi.

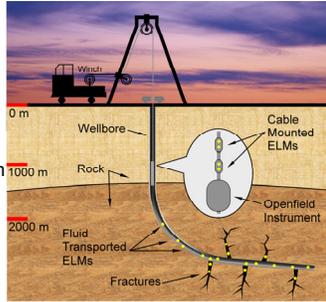
1 Background Information

Demand for Oil Well Monitoring

- Enhance oil extraction efficiency
- Interested parameters: temperature, pressure, chemical concentrations
- Traditional logging method: wireline logging, crosswell imaging, aggregate data with limited detection range / resolution
- Solution: environmental logging microsystem (ELM) distributed for downhole environmental monitoring

Example Environmental Conditions in an Oil Well

Parameter	Targets
Pressure	50 MPa (7,250 psi)
Temperature	75 - 125 °C
Salinity	API standard brine (8 wt% NaCl & 2 wt% CaCl ₂)



Example Application Scenarios for ELM:
 • Tethered to cable
 • Distributed in wellbore and fractures

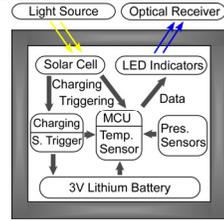
2 System Design

System Configuration

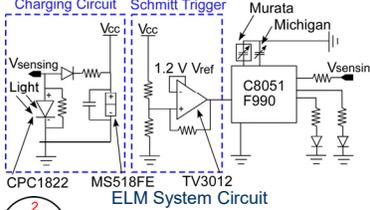
- Silicon Labs C8051F990 MCU with T. sensor
- One or two capacitive pressure sensors
- Photodiode for wireless charging and triggering
- Schmitt trigger for charging protection
- Seiko Instruments Li coin cell battery
- Two LEDs for data reporting

ELM Specifications Table

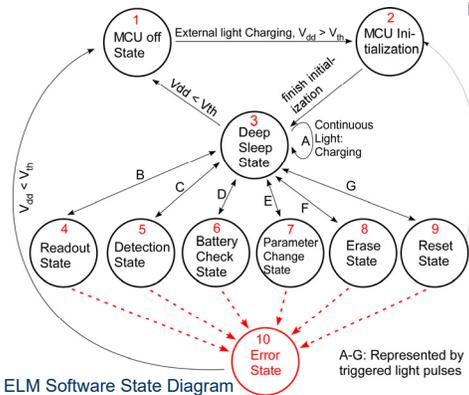
Physical Parameters	
System stack size	$7.2 \times 6.6 \times 5.5 \text{ mm}^3$
Integration topology	Polyimide flexible PCB
Electrical Parameters	
Battery nominal voltage	3.0 V
Current (Active, ADC off, 125° C)	180 μA
Current (Sleep, RT)	5 μA
Current (Sleep, 125° C)	12 μA
Battery capacity & size	3.4 mAh Φ5.8 mm x 1.8 mm



ELM Block Diagram



ELM System Circuit

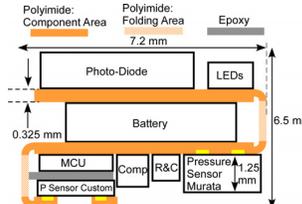


SEM image of U. Mich. pressure sensor (0-7500 psi, ≈3500 fF full scale)

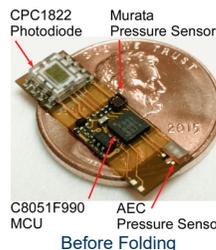
3 System Integration and Packaging

System Integration

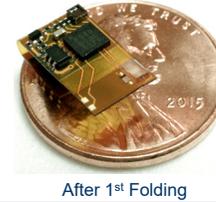
- Folded flexible polyimide PCB



Configuration of Folded PCB



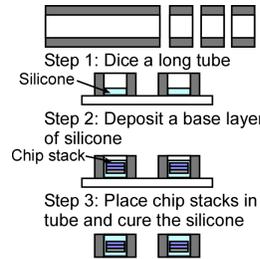
Before Folding



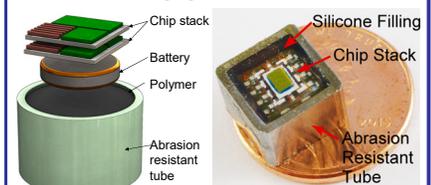
After 1st Folding

System Packaging

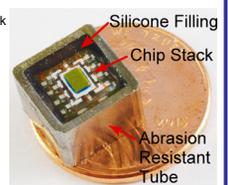
- Tubular hybrid metal / polymer package
 - Soft polymer: pressure coupling and low temp. coefficient
 - Metal shell: Mechanical support & abrasion tolerance.
 - Optical & EM links.



Packaging Process Flow



Packaging Concept

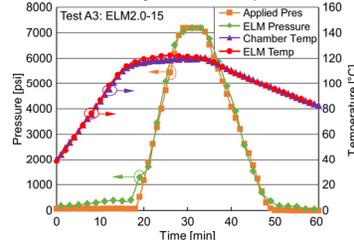


ELM in Package, 9.5 x 9.5 x 6.5 mm³

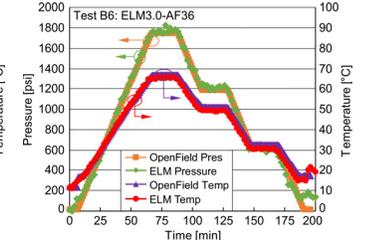
4 Laboratory and Field Test Results

Systems Tested in High Pressure High Temperature (HPHT) Environment

- Packaged systems tested at sponsor's laboratory facility, and in a brine well at depths up to 1235 m (limited by available cable length)
- Packaged systems survived temperatures up to 150°C , pressure up to 10,000 psi for up to 15 hours, in API standard brine, Isopar[®]-L, fracking gel, silicone oil, and a proprietary mud solution
- Packaged systems survived in brine well tests at up to 70°C and 1800 psi for 12 hours. Some hydrocarbons present in well.



Example laboratory test results



Example brine well test results (Openfield instrument used as reference)

Acknowledgement

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Patent Application

Environment Logging System, US Patent Pending, Application No. 15/410,724, submitted Jan. 2017.

Publications

- [1] Y. Sui, A. Benken, Y. Ma, A. Trickey-Glassman, T. Li, and Y. B. Gianchandani, "An Autonomous Environmental Logging Microsystem (ELM) for Harsh Environments," in preparation.
- [2] M. Choi, Y. Sui, R. Meredith, Y. Ma, G. Kim, D. Chapman, D. Blaauw, Y. B. Gianchandani, and T. Li, "Autonomous Microsystems for Downhole Applications: Design Challenges, Current State and Initial Test Results," in review.