A Microtensiometer for Large-Range Measurement of Water Potential in Plants, Soils and Other Materials

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Sensor Development Team

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What is Water Potential?

• Water potential refers to the physical status of water that is affected by dissolved solutes (sugars, mineral ions) or by the absorption of water in a material compared to pure water.

• It is a measure of moisture and affects the direction and ease of water movement. For example, water moves from a wet part of a sponge or a soil to a dry part due to the gradients in water potential.

• Analogous to electricity, water potential differences are equivalent to voltage gradients so they are critical to the role of water in plants and materials.
Why Measure It?

• Water potential is important in materials such as soil and plants as it is a measure of the stress in plants due to drying soil during droughts.

• The stress level affects plant growth and productivity, so measuring and controlling it is important to optimizing plant growth and irrigation efficiency.
Why Measure It?

It is also an important fundamental measure of the moisture of other physical materials such as food stuffs like cereals, crackers, etc. So there may be many uses for a good water potential sensor.
What Do We Use Now to Measure Water Potential in Soils?
What Do We Use Now for Plants?

A Plant Pressure Chamber
Accurate but expensive, manual and takes several minutes per measurement. So only an occasional “snapshot” of a dynamic system.

From Plant Physiology Online: http://5e.plantphys.net/article.php?ch=3&id=29

Photo – Soil Moisture Corp
www.soilmoisture.com
The Ideal Water Potential Sensor

- Versatile and low power consumption
- Measure continuously for great sampling over time
- Measure accurately over a wide range of stress
- Report data real-time or near-real-time with a simple output (millivolts) or wirelessly to a network
- Monitor a key physical property of material or plant water potential that is directly related to material or plant characteristics or performance
- Be rugged, stable over time
- Relatively easy to place and maintain
**Goal** – develop a microfluidics-based microtensiometer (mm scale) to monitor water potential continuously.
Sensor Concept

Based on the well known principle of the soil tensiometer.

• An enclosed volume of pure water equilibrates with an external material (soil, plant, whatever) through a permeable exchange surface.

• If the external material (e.g. soil) is drier (i.e. lower water potential) then water will be pulled out of the sensor, setting up a tension.

• The drier the material the more tension will be measured.
Our Approach: MEMS-based Microfluidic Sensor

- **Micro-Electro-Mechanical System-based technologies** – aided by IC fabrication processes
- Sub-mm range devices
- Started with pressure sensor fabrication in 1970s, refined in the 1990s with some key process developments, e.g. DRIE
- Materials – crystalline silicon, polysilicon, silicon nitride, oxide, glass, etc.
- Micromachining used for: semiconductors, sensors, actuators, accelerometers, biomedical devices
Micro-Electro-Mechanical Systems (MEMS) are complex integrated devices manufactured like computer chips. The microsensor is designed for MEMS manufacture.

Smart System Technology & Commercialization Center
(www.itcmems.com)
Example of a microsystems development and manufacturing center
Microfluidic Water Potential Sensor: Design Schematic
Sensor Microfabrication

Cornell Nanoscale Science & Technology Facility
Sensor Microfabrication

Molecularly nanoporous membrane scaffold manufactured with photolithography and deep silicon etching

Pressure sensor: polysilicon piezoresistors on silicon diaphragm
Sensor Preliminary Testing Results

Membrane Stability Testing

Empty and Filled Cavities

Tensions stable down to -100 bar

Pressure Sensor Testing

Pressure sensor testing using externally applied positive liquid pressures from 0-22 MPa shows a linear response of output voltage ($\Delta V$).
Sensor Preliminary Testing Results

Microtensiometer – Integrated Device

Prototype testing: pressure sensor responds to change in external vapor pressure above wick membrane
Microsensor Integrated Design

2 cm

1.2 cm

2 x 5 mm
Dummy Xylem Sensor Embedding Studies to Determine Optimal Method to Embed in Plants

Dummy sensor embedded in trunk of grapevine by 2 methods
Ongoing Work and Future Experiments

- Sensor membrane shown to be stable down to -100 bars of tension; in some cases, we have shown tensions measureable down to -200 bars.
- Pressure sensor shown to have linear operation from 0-200 bars of positive pressure.
- Integrated microsensor fabrication complete.
- Initial prototype testing shows response to sub-saturated vapor.
- Embedding studies to determine best trunk-insertion responses.
- Test sensor performance vs. existing techniques.
- Develop sensor housing for probes for plant, soil and other materials.
Potential Impacts

- Aiding our understanding of how plants respond to water stress.
- Characterizing the spatial and temporal dynamics of water status of crops to optimize irrigation and water use efficiency as water becomes more scarce.
- Applications to forest ecology – Understand and monitor water stress effects on large scale energy, water and CO₂ fluxes with the atmosphere.
- Dramatically improve soil water potential sensors.
- Improve the efficiency of monitoring the water status of other materials such as food stuffs.
## Acknowledgements

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