Atmospheric Humidity Energy Harvester 2.docx

Robert Brian Dopp
DoppStein Enterprises Inc.
1925 Fields Pond Glen
Marietta, GA 30068
Tel: 770 649 1933
RBDopp@doppstein.com

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ABSTRACT:

Omega Energy has developed a solid-state energy harvester which uses water vapor as a fuel, producing electrical power through a series of reactions on transition metal suboxide intermediates. The anode is made from metal suboxide and the cathode from a different transition metal suboxide. The separator is any polymer layer that will transport aquatic ions. It will produce energy as long as water vapor is present. The transition metal suboxides catalyze the dissociation of water molecules, releasing electrons and oxygen gas from the anode and consuming electrons and releasing hydrogen from the cathode.

Field of Invention:

Energy Harvesters are devices that do not store energy, but rather gather it from the environment. Examples include solar power, thermal energy, wind energy, salinity gradients, kinetic energy, and RF capturing devices like the crystal radio among others. These devices store energy rather than harvest it.

This invention uses various suboxides of transition metals that allow non-integer valence states in the mass of their crystal structures. Charge is transferred on the surface of the various suboxides from water vapor adsorption and subsequent dissociation driven by the suboxides. Oxygen from the dissociated water molecules in the anode or from the environment (depending on application) enter the suboxide vacancies and assist in the vacancy balance within the crystal. Power is continuous as long as the electrodes are in a humid environment.

General Theory of Operation:

We use several transition metal suboxides that have an average valence less than the integer value for that element's oxide: Thus, the name "suboxide". This valence value is the average over the crystal mass. A suboxide crystal contains less oxygens (called vacancies) in the bulk of the crystal structure than in a common oxide, thus resulting in an average metallic valence that is not an integer. This oxygen imbalance combined with the surface metal hydroxide gives each compound an electronegativity that differs for each compound resulting in a different "Point of Zero Charge" (zpc), which expresses itself as different pH values for adsorbed water on the surface of the powdered suboxides. The active cathode material is less electronegative than the anode material, and thus is "electropositive" relative to the anode. The charge is separated using any material that will transfer protons (H^+). We have used Nafion successfully, but now use hydrated, unplasticized cellophane, which will transport any water-soluble ion. In our case, only protons are transferred. The anode and cathode both also contain carbon to reduce the internal impedance of the system. Both the anode and cathode reactions are well characterized and are reactions of cascading vacancies and electrons within the crystal structures.

Anode Mechanism:
A tungsten suboxide catalyzes the dissociation of a water molecule into a singlet oxygen, two protons and two electrons, which return to the cathode via an external circuit.

H_2O <-$\overset{WOx}{}$-> $\frac{1}{2}O_2 + 2H^+ + 2e^-$

The titanium suboxide also splits water into an singlet oxygen, two protons and two elections by

H_2O -$\overset{TiOx}{}$-> $\frac{1}{2}O_2 + 2H^+ + 2e^-$ giving a combined equation of:

H_2O -$\overset{TiOx\ \&\ WOx}{}$-> $\frac{1}{2}O_2 + 2H^+ + 2e^-$

Both the titanium and tungsten reactions are a result of complex cascading vacancies within the crystal structure. Both the singlet oxygen and the proton migrate to the cathode driven by diffusion through the separator.

Cathode Mechanism:
Water vapor enters the cathode. The oxygen reacts with a proton from the anode catalyzed by the tungsten suboxide, consuming two electrons and liberating a water molecule. This is the reverse reaction seen in the anode. Both the oxygen and the proton come from the anode.

$\frac{1}{2}O_2 + 2H^+ + 2e^-$ <-$\overset{WOx}{}$-> H_2O

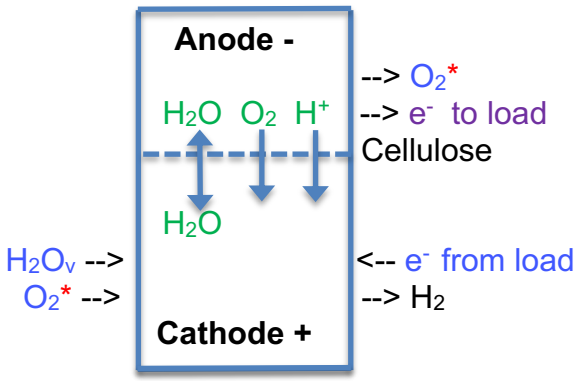
This catalysis is due to cascading vacancies within the tungsten suboxide crystal structure.

The cobalt suboxide also catalyzes another electron consuming reaction where a proton and electron combine to make hydrogen gas. This catalysis is also a vacancy cascading reaction series.

$2H^+ + 2e^-$ -$\overset{CoOx}{}$-> H_2

It is also thought that a combined catalytic reaction with both the cobalt and tungsten suboxides react with adsorbed water to form hydrogen gas and consume electrons. The water molecules, both adsorbed and created, migrate to the anode by diffusion.

Pictorial Presentation:
In the block-diagram below, I show that which comes into the cell, out of the cell and through the cell using colored ink to show that which is entering, leaving or transferred within the cell.



Note: * When in flowing air design rather than the anoxic design.

Entering the cell: The cathode inhales water vapor (H_2O_v). The cathode also accepts electrons (e^-) from the load.

Internal transfers are the protons (H^+) produced in the reactions and liquid water (H_2O) on the surface of the powdered reagents through the separator and into the anode. A singlet oxygen is also produced, which will combine into an O_2 that migrates to the cathode. The driving force is both from Knudsen diffusion and the concentration gradient.

Leaving the cell: Some of the oxygen (O_2) from the anode and hydrogen (H_2) from the cathode are exhaled in gaseous form. Electrons (e^-) leave the anode to do work in the load.

Electrode and Cell Making:

The project started with pellets made in a piston-cylinder type compression apparatus. It has evolved into making electrodes using a rolled process making thin sheet anodes and cathodes all bound with unsintered PTFE powder. The powders for the electrode (anode or cathode) are blended for two minutes in a high sheer blender at 20,000 rpm. Then acetylene black carbon is added and gently mixed in. This mixture is then applied to a rolling press as a thin, uniform sheet of powder. The mill is under 650 pounds compression force. The result is an electrode sheet that is about 0.9 mm thick and very uniform. From this, disks are punched out and placed within a polypropylene grommet which is compressed to 2000 pounds to produce the final electrode. Between the anode and cathode is a disk of hydrated, non-plasticized cellophane. All parts are “glued” together using a latex-based carbon conductive paint that has been diluted 50% with water.

This assembly is then placed inside the cell body to complete the finished cell with water vapor entering the cathode half of the cell through a sheet of unsintered porous PTFE.

Cell Formulation

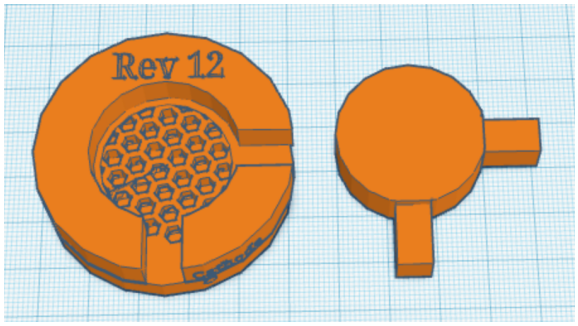
Our cell uses three transition metal suboxides; $WO_{2.9}$, Ti_4O_7 and Co_3O_4 in the ratios listed in **Table 1** . They primarily act as catalysts for the chemical dissociation of water vapor on the surfaces of the powders, liberating electros from the anode and consuming electrons in the cathode. Internal charge is transferred by protons produced in the anode and migrate through the hydrated cellulose separator to the cathode.

Anode	Wt, g	%
$WO_{2.9}$	4.9	17.7%
Ti_4O_7	16.4	59.4%
Teflon	5.8	20.9%
Carbon	0.53	1.9%
Cathode	**Wt, g**	**%**
$WO_{2.9}$	28.2	56.6%
Co_3O_4	12.0	24.1%
Teflon	8.7	17.4%
Carbon	1.0	1.9%

Table 1: Present Control Formulation

The tungsten suboxide is present in both electrodes, but at very different loadings and catalyzing in opposite directions.

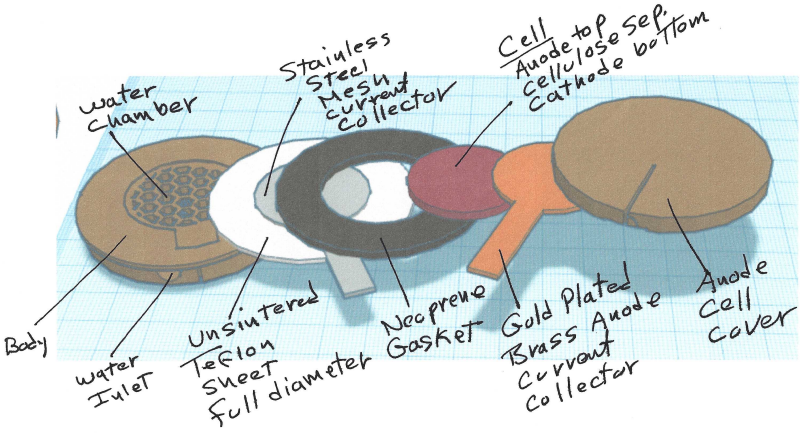
Cell Design for Moving Humid Air:



The cell is printed using PETG (Polyethylene) to be sure it is moisture stable. The CAD drawing shows the air being distributed to the entire surface of the cathode. The inlet is to the left, so not visible in this view. A cathode current collector made of a fine stainless-steel screen is laid on the bottom and is shaped rather like a lollypop with the contact strip extending downward in this view. Then, a sheet of porous carbon paper is laid over that to protect the electrode from damage of the woven character of the screen. The cathode, separator and anode are then laid over the carbon in that order. Next is another “lollypop” shaped current collector made of thin brass that has been heavily gold plated.

Cell Design for Anoxic Discharge:

The cell is also printed using PETG (Polyethylene) to be sure it is moisture stable. The CAD drawing shows parts in an exploded view, then in cross section. The cell is represented by the purple disk in the center. This cell stands on edge when functioning, so the cathode is bathed in a 100% RH. The white sheet is porous Teflon preventing liquid water from reaching the cell, but allowing water vapor to pass freely to the cell.



Performance Characteristics:

Our cell is still in the development stage. The present "Control" design has the following table of characteristics.

Outside Diameter	22.2 mm (7/8")
Surface Area	3.88 cm^2
Thickness of full cell	2 mm
Exchange Potential (E_o)	200 to 250 mV
Limiting Current	150 to 125 uA/cm^2
Power Density	9 to 12 uW/cm^2
Ohmic Impedance	9 to 12 Ω-cm
Max E_o ever recorded	550 mV
Max Power Density ever recorded	30 uW/cm^2

Applications:
An article "**Powering Implantable and Ingestible Electronics"** was found that describes many examples of subdermal mechanisms used today. The thrust of the article is various ways to power these devices. Some have much too high a power rating for our cell, but several are in the uW or uA range. Below are the devices within the range that could be provided by our cell listed in the paper. Below are the ones within our power or current output range. Our cell runs well with no gaseous oxygen, but 100% RH.

Table 1: Power requirements of implantable biomedical electronic devices.

Implantable/Ingestible device	**Power requirement**
Deep brain stimulator (DBS)	100 μW
Intraocular pressure (IOP) monitor	200 nW–200 μW
Cochlear implant	100 μW–10 mW
Pacemaker	10–30 μW
Implantable cardioverter defibrillator (ICD)	50–500 μW
Implantable drug delivery system	100 μW–1 mW
Artificial urinary sphincter	200 μW
Bone healing assist	10 uA

Most of our discharge experiments are at dead-short, which gives ASec (Coulombs) data but with no power numbers, since power is the product of current times voltage. An experiment is now underway in an anoxic, 37°C environment over a 100kΩ load. It has now run for 9 weeks and delivered 204 uWHr. Continuous power output from this cell is about 0.11 uW discharge with no sign of sagging performance. We would need to develop a larger surface area cell to reach the general level needed.

The cell would also lend itself to powering low-power amplifiers or sensors as long as the environment is very humid. So anywhere in SE Asia, much of India and much of central & south America.

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Summary:

- The Omega Energy Harvester is capable of continuously producing power from vapor.
- The cell runs in humid air with oxygen also [present or in an anoxic environment.
- Moderately higher temperatures make the cell run better, as the Arrhenius relationship would suggest.
- It is relatively easy to manufacture and has a small physical footprint.
- Could run a low power transmitter, receiver or other sensing devices.
- Would work well in the warm, anoxic environment of subdermal devices.
- Series-parallel arrangements would deliver higher voltage and power.
- Three patents have been issued on the concept:
  - US 9,029,026 B2 Michael Lee Horovitz May 12, 2015
  - US 10,879,735 B2 Michael Lee Horovitz *et al* Dec 29, 2020
  - US 11,476,487 B2 Robert Dopp *et al* Oct 18, 2022