Abstract

Primary zinc-air battery technology has characteristics that can make it an attractive addition to the portfolio of battery chemistries used in handheld electronic products. The advent of Diffusion Air Manager technology, advances in the rate capability of the air electrode, and the introduction of high capacity cell designs with thin form factors are developments bringing primary zinc-air closer to commercialization for portable products. The status of primary zinc-air cell and battery technology is discussed and implementation in portable consumer products is demonstrated.

Introduction

Today’s handheld electronic devices are a challenging application for batteries because portable products have very demanding performance requirements in several wide ranging categories — energy density, power density, safety, environmental compliance and cost. The fact that battery performance continues to be a topic of discussion in electronic product performance reviews provides an indication of how difficult it is to develop high performance batteries that can satisfy the needs of portable applications. The search for better power sources has never been more intense. One promising primary battery technology in this search is the zinc-air system.

The primary zinc-air system has demonstrated many of these properties and proven itself commercially as an excellent power source in hearing aids. Zinc-air button cells dominate this application even over lithium button cell competitors. However, in attempting to extend this type of success to other applications, one operating idiosyncrasy of zinc-air has been an insurmountable barrier. When the air-breathing electrode in a zinc-air cell is exposed to the atmosphere to allow oxygen into the cell to fuel the electrochemical reaction, transpiration of water vapor occurs between the electrolyte and the atmosphere. Depending on the ambient temperature and relative humidity, zinc-air cells can fail within days because either too much water is lost from the electrolyte or too much water is absorbed by the electrolyte.

Figure 1. Comparison of energy storage capability for various primary battery systems (ref. 1).

“Diffusion Air Manager” technology is a recent development that overcomes this long-standing limitation of the zinc-air system. Diffusion Air Managers can effectively isolate zinc-air cells from negative interaction with the atmosphere while providing sufficient oxygen as needed. However, the key strength of the Diffusion Air Manager solution is that it solves the water-transpiration/oxygen-supply problem in a way that meets a long list of equally challenging commercial criteria — small, light, simple, unobtrusive, transparent to the user, and low cost. Satisfying all of these elements allows zinc-air with Diffusion Air Managers to be a practical power solution in the portable electronic market.

After the water transpiration issue, the next area of im-
importance in zinc-air development is its power capability. Present state-of-the-art power capability of the zinc-air system lies between alkaline/manganese dioxide primary cell and rechargeable cell performance making it a candidate for many applications. However, the closer a primary system can get to rechargeable cell power characteristics, the greater the opportunities for even wider application. The air cathode is one area under active development that holds promise for higher rate capability.

The third area to review in evaluating the status of primary zinc-air technology is cell design and battery form factors. The ability to construct batteries with runtimes and form factors that complement the electronic product they serve may be an important design edge with primary zinc-air.

Diffusion Air Manager Technology — Enabling Zinc-Air Cells for Use in Portable Devices

The air electrode in a zinc-air cell consists of three main structures, a hydrophobic layer, a hydrophilic layer and a current collector. Figure 2 illustrates these features in a cross section view of an air cathode.² The hydrophobic layer functions as a gas-permeable, liquid-proof boundary between the atmosphere and the cell’s electrolyte, which is an aqueous solution of potassium hydroxide. The hydrophilic layer’s function is to promote the electrochemical reduction of oxygen to a species that can react with the zinc anode; it is composed of high surface area carbon with finely dispersed Teflon particles and catalysts.

![Figure 2. Cross-section of an air electrode.](image)

The air electrode is designed to be gas permeable and allow oxygen to pass from the air side to the electrolyte for use in the electrochemical reaction. However, in addition to oxygen, the air electrode also allows water vapor to pass between the electrolyte and the surrounding atmosphere. The rate and direction of the water vapor movement is controlled by the concentration of the electrolyte and the relative humidity conditions in the surrounding air. For a typical zinc-air cell design, the electrolyte has an equilibrium point of about 50% relative humidity (RH) at room temperature i.e. there is no water vapor transfer under these conditions. When the ambient relative humidity is below the 50% relative humidity level, water vapor will migrate through the air electrode out of the electrolyte. This condition is referred to as “dry out” and it can reduce cell power and capacity to the point of failure. At relative humidity levels above 50%, the electrolyte can gain water from the air. The water vapor passes through the air electrode into the electrolyte. This condition called “flooding” can block oxygen access affecting capacity and power, and in severe cases cause cell leakage.

![Figure 3. Conceptual representation of a Diffusion Air Manager.](image)

Diffusion Air Manager’s ability to control the transmission of water vapor between zinc-air cells and the atmosphere is based on gas diffusion laws. Figure 3 provides a conceptual view of a Diffusion Air Manager. Zinc-air cells and a fan are sealed in a vapor tight housing with two small diameter tubes as the only openings to the outside atmosphere. Water vapor transmission with this configuration can only occur by diffusion through the tubes. With the fan off, the cells are well isolated from the negative effects of humidity levels in the atmosphere. Alternately, oxygen for the cells is provided in sufficient amounts via this same pathway when the battery is being discharged by turning the fan on. Water vapor transmission rates can be further controlled during discharge by supplying the minimal amount of ambient air needed to satisfy the oxygen requirements of the zinc-air electrochemical reaction.

![Figure 4](image)

Figure 4 is a quantitative graphical way of expressing the performance of the Diffusion Air Manager with specific zinc-air cell designs. The graph provides activated storage life expectancy of a cell for different temperature and relative humidity conditions. Note that for this particular cell design, activated life is extremely brief - the cell is reduced to 80% of its original capacity after only several days of exposure to 30% RH at room temperature. However, when the cell is housed in a Diffusion Air Manager, activated storage life improves dramatically. Several days become two years of storage life at room temperature and extremes of 30% or 70% relative humidity. Note the trend on the graph for the activated storage life is for extended life under less severe humidity levels. This order of magnitude extension of the activated storage life means that the primary zinc-air system can now become a practical power source for use in a large array of electronic products.
housing is used for the cell. The main parameters in cell construction for a zinc-air cell. In this design a plastic container acts at this time. Figure 8 is an example of flat prismatic cell packaging methods for the cathode material, cathode morphology and current collectors offer opportunity for higher power air electrodes. These are promising areas of active exploration.

With regard to cell form factor, zinc-air cells have been made in flat prismatic and cylindrical shapes. In addition, cell size has a high degree of flexibility because scaling to larger sizes comes without the safety concerns associated with many other battery systems. Three main reasons contribute to this. The cathode is porous to air, which precludes many problems associated with a sealed system becoming a pressure vessel. The electrolyte, an aqueous solution of potassium hydroxide, is not flammable. Short circuits do not easily lead to thermal runaway because power tends to be limited by air diffusion issues.

A thin prismatic shape appears to be a popular form factor for battery configurations in many electronic products at this time. Figure 8 is an example of flat prismatic construction for a zinc-air cell. In this design a plastic housing is used for the cell. The main parameters in cell design are providing sufficient cathode area to satisfy the power requirements and sufficient zinc volume to meet capacity requirements. Note that additional ampouls of capacity are gained by increasing only one active component, the zinc anode. So small increases in the thickness of the cell design can achieve dramatic capacity increases.

Exploration of zinc-air cell sizes and shapes for portable applications is still in its infancy. Historically, most work on zinc-air has been concentrated on two ends of the size spectrum, very small button cells and very large electric vehicle cells. Key applications and development of cell packaging methods will drive zinc-air cell design for portable devices.

### Beyond Button Cells — Developing High Capacity, High Power Zinc-Air Cells

Since zinc-air button cells are the only widely commercially available zinc-air battery product at this time, perception of zinc-air cell performance is largely based on this product. Unfortunately, one area that can be misunderstood is the power capability of the system. Zinc-air button cells are very low rate; however, this is by design in the button cell. The zinc-air system has good power characteristics as evidenced by investigations of zinc-air for electric vehicle use. Exposing the cathode and providing it with sufficient air is necessary to maximize the power capability of a zinc-air cell. Present state-of-the art air cathodes are capable of continuously delivering 80 mA/cm² at 1.00 V. So battery power is well above alkaline/manganese dioxide. However, higher power performance is being explored because higher power can further increase the commercial utility of zinc-air, extending the possible areas of application. Work on catalysts, processing methods for the cathode material, cathode morphology and current collectors offer opportunity for higher power air electrodes. These are promising areas of active exploration.

A listing of consumer electronic products for which a primary zinc-air battery may be suitable is presented in Figure 5. In this list, average runtimes obtained with the existing battery are compared to projected runtimes for a conceptual primary zinc-air battery. Note that many of the battery comparisons involve rechargeable batteries. A high capacity zinc-air battery endowed with extended operating life makes it possible to rethink some products that have been designed to run on rechargeable batteries. This is particularly true for electronic products that are used very intermittently. In addition, primary zinc-air may fill the performance gap between the choice of alkaline and lithium metal batteries.

Beyond the long runtime, the zinc-air primary battery offers enhanced portability, convenience and value compared to the rechargeable battery option. These advantages are compelling and tangible when experienced as: light battery weight, no charger to carry, no extra batteries to juggle, the product is always ready when needed, no logistics to plan in locating an AC power outlet for charging, and a much lower initial product purchase price compared to the rechargeable battery option. The camcorder was selected from the list in Figure 5 to explore the application of an actual zinc-air battery in practice. A representative camcorder with an LCD display requires a nominal 6 volts at an average power of 3.3 W and peak power of 8 W.

To fit the camcorder battery form factor, a thin prismatic zinc-air cell with a plastic housing was used. See Figure 8. To meet the power requirements, an air cathode capable of 80 mA/cm² at 1.00 V was used and the cell design was engineered so that zinc utilization above 75% at 0.5 A was achieved, providing a nominal capacity of 8 Ah.

The battery was formed by stacking the cells in pairs with a space of 0.060 inches between opposing air cathodes. This plenum allows circulating air to reach the cathodes. Six cells are connected in series. The Diffusion Air Manager is implemented by completely enclosing the six-cell pack in a plastic housing with two tubes molded.
into the plastic battery housing leading to an off-the-shelf blower adjacent to the cells. One tube interfaces with the intake of the blower while the other tube interfaces with the exhaust. Figure 9 provides specifications for this battery pack.

To the user, this zinc-air battery pack operates like a conventional primary battery and the camcorder is operated in the usual manner. The cycling of the fan and the operation of the Diffusion Air Manager is completely transparent to the user. The differences that the user does notice are that the battery pack is very light, the camcorder is always ready to use, and there are no concerns about where and when to charge the battery and no charger to carry.

Figure 5. Primary zinc-air batteries can increase runtime and convenience for a number of portable devices.

Another aspect of patented Diffusion Air Manager technology implemented in the battery is a method for controlling activation of the air mover. In this case, circuitry turns the blower on when the oxygen concentration inside the battery housing reaches the low limit and turns the blower off when the oxygen level is restored. Since, the oxygen level in the battery housing corresponds to the battery voltage, no exotic circuitry is needed. A simple voltage comparator can perform this function. In this implementation, the blower comes on when the battery voltage falls to 6.2 V and turns off when the battery voltage reaches 6.5 V. The circuit has two advantages. The fan on/off function is easily interfaced with the device the battery is operating and significant energy savings result from this control strategy compared to constantly running the fan.

To the user, this zinc-air battery pack operates like a conventional primary battery and the camcorder is operated in the usual manner. The cycling of the fan and the operation of the Diffusion Air Manager is completely transparent to the user. The differences that the user does notice are that the battery pack is very light, the camcorder is always ready to use, and there are no concerns about where and when to charge the battery and no charger to carry.

Figure 6. Graphical discharge data of various camcorder batteries showing service hours in a User Test.

<table>
<thead>
<tr>
<th>BATTERY</th>
<th>ENERGY (Wh)</th>
<th>WEIGHT (g)</th>
<th>SPECIFIC ENERGY (Wh/kg)</th>
<th>VOLUME (cm³)</th>
<th>ENERGY DENSITY (Wh/l)</th>
<th>INDUSTRY RUNTIME (h)</th>
<th>USER TEST RUNTIME (h)</th>
<th>NUMBER OF TAPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std OEM NiCd</td>
<td>4.8</td>
<td>142</td>
<td>34</td>
<td>67</td>
<td>87</td>
<td>1.4</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Accessory NiCd</td>
<td>10.8</td>
<td>290</td>
<td>37</td>
<td>187</td>
<td>58</td>
<td>2.6</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Accessory NiMH</td>
<td>21.6</td>
<td>340</td>
<td>64</td>
<td>153</td>
<td>141</td>
<td>5.5</td>
<td>3.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Std OEM Li-ion</td>
<td>5.0</td>
<td>68</td>
<td>76</td>
<td>54</td>
<td>176</td>
<td>1.4</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>6 AA LiFeO₂</td>
<td>16.5</td>
<td>145</td>
<td>114</td>
<td>187</td>
<td>88</td>
<td>4.6</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td>6 AA Alkalines</td>
<td>9.4</td>
<td>210</td>
<td>45</td>
<td>187</td>
<td>50</td>
<td>2.6</td>
<td>0.9</td>
<td>1.5</td>
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<tr>
<td>6 AA High Rate Alkaline</td>
<td>10.8</td>
<td>215</td>
<td>50</td>
<td>187</td>
<td>58</td>
<td>3.0</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Primary Zinc-air</td>
<td>50.0</td>
<td>235</td>
<td>213</td>
<td>196</td>
<td>255</td>
<td>15.0</td>
<td>8.3</td>
<td>7.5</td>
</tr>
</tbody>
</table>

1 Industry runtime is measured in continuous record of a fixed subject with the LCD panel off. Test is performed with actual batteries. Power averages 3.6 W.
2 User test runtime is measured with a script using the LCD panel, rewind, playback and record functions. Runtimes are actual batteries. Test is performed with actual batteries. Power averages 5.4 W.
3 Volume and weight includes battery holder and cells.
4 Equivalent number of 2-hour tapes used in the Industry Runtime Test to nearest half.

Figure 7. Primary and secondary batteries for camcorders.
Figure 7 provides a comparison of the specifications for several types of camcorder batteries. The zinc-air camcorder battery compares favorably to other primary and secondary batteries and indicates zinc-air can add extra dimensions of portability, convenience and value to mobile products. The discharge data from the column entitled User Test appears in Figure 6. The data show that the primary zinc-air battery can record 7.5 two-hour tapes and last well over a year in a range of environments. While runtime and energy density advantages are readily conveyed quantitatively in these figures, enhancements in convenience, portability and value are also significantly enhanced. Perhaps the best method of conveying these advantages is through the experience of actually using the zinc-air battery.

Future Zinc-Air Battery Designs
Zinc-air battery technology for portable electronic products is in its infancy. Diffusion Air Manager technology has opened the door for the zinc-air electrochemical system to participate in the dynamic and growing portable consumer electronics market. The success of zinc-air button cells in hearing aids serves as an indication of how this battery technology can come to commercially dominate an application and grow an industry. Developments which will further advance the position of zinc-air in portable devices include: the introduction of more cell designs with form factors complementary to electronic products, cell designs that further increase energy and power density through better zinc utilization and packaging, air electrodes with high rate capability, and the development of air moving devices specifically designed for zinc-air batteries.

The expectation is that the zinc-air system will continue to make strides in energy and power density and additional opportunities for application will appear with new electronic devices. The camcorder battery example is a useful and compelling illustration of the potential and value of primary zinc-air technology for portable products at its present stage of development.

**ELECTRICAL**
- Open Circuit Voltage: 1.4 V
- Nominal Operating Voltage: 1.2 - 0.8 V (design using 1.1 V)
- Cutoff Voltage: 0.75 V
- Capacity: 8 Ah at 0.5 A (+25 °C)
- Energy: 8.8 Wh at 0.5 A (+25 °C)
- Max Continuous Current: 1.0 A
- Energy Density: 284 Wh/kg
  - 440 Wh/l

**AIR MANAGEMENT**
- Required for operation in battery

**MECHANICAL**
- Weight: 0.068 lbs (31 g)
- Volume: 1.22 in³ (0.020 l)
- Dimensions (L x W x H) inches: 2.97 x 1.68 x 0.245
  - millimeters: 75.4 x 42.7 x 6.22

**ENVIRONMENTAL** (For cell in air manager)
- Temperature Operating: 0 °C - +45 °C
  - Storage: 0 °C - +50 °C
- Relative Humidity Operating: 5 - 90%
  - Storage: 5 - 95%
ELECTRICAL

- Open Circuit Voltage: 8.4 V
- Nominal Operating Voltage: 4.8 - 7.2 V (design using 6.2 V)
- Cutoff Voltage: 4.5 V
- Capacity: 7.5 Ah at 0.5 A (+25 °C)
- Energy: 46 Wh at 0.5 A (+25 °C)
- Capacity Retention: Capacity loss less than 1% per month
- Max Continuous Current: 1.0 A
- Energy Density: 204 Wh/kg
  235 Wh/l

AIR MANAGEMENT

- Patented Diffusion Air Manager
- Included in battery

MECHANICAL

- Weight: 0.5 lbs (226 grams)
- Volume: 11.9 in³ (0.196 liters)
- Dimensions (L x W x H):
  - inches: 3.51 x 1.88 x 1.80
  - millimeters: 89 x 48 x 46

ENVIRONMENTAL (For cell in air manager)

- Temperature
  - Operating: 0 °C - +45 °C
  - Storage: 0 °C - +50 °C
- Relative Humidity
  - Operating: 5 - 90%
  - Storage: 5 - 95%

**Figure 9. Model 6V08 Primary Zinc-Air Battery Specification Sheet.**

References