ReVolt Portable Battery

Technology Brief

OVERVIEW

Rapid advances in consumer electronics continuously bring products with bigger and brighter color displays, camera and gaming functions and high-speed communication. As these applications become more sophisticated they consume more energy, which drives the need for a new generation of portable-battery.

Current fuel cell or battery technology cannot keep up with the demand to provide sufficient power, long run time and remain compact – while at the same time being competitive with respect to materials and production costs.

ReVolt's breakthrough technology has created the foundation for a superior power source that meets this demand.

Limitations of current technology

Current battery and fuel cell technology faces a number of limitations in matching the pace of consumer electronics development.

- Traditional secondary batteries, such as the Li-ion and Ni-metal hydride batteries, have reached their inherent potential. There seems to be a cap on further improving this technology.
- New solutions based on fuel-cell technology face significant barriers related to material cost and performance.
- For the portable power market the most promising approach seems to be a combination of battery and fuel cell technology: a metal-air battery. Such batteries have a high potential for energy density and low production cost. But the batteries available in the market today are primary (non-rechargeable) and mainly used in low power applications such as hearing aids.

Several innovative solutions have been introduced for the metal-air technology, which seems most promising. But successful commercialization depends on overcoming the following barriers:

- Inability to deliver sufficient power.
- High degradation rate and loss of power over time.
- Lack of an adequate option for recharging. Non-electrical refill solutions are not well suited for the use in small portable applications.
- Space and power consuming peripherals make them unsuitable for the portable electronics market, and increase cost.

ReVolt breakthrough

ReVolt has developed a metal-air battery that overcomes the above barriers, and as such represents a significant leap in technology. ReVolt's prototype for consumer electronics delivers:

- POWER: High reaction rates on the electrodes for both charge and discharge. Full cell batteries have been demonstrated with high power levels.
- LIFETIME: Long battery life due to stable reaction zone, low dry-out and flooding rate and no pressure build-up problems. The technology has the potential of up to three times the energy density of Lithium-ion batteries at a comparable or lower production cost.
- RECHARGEABILITY: Controlled deposition with high mechanical stability.
- COMPACT SIZE: No need for peripherals such as cooling fans or temperature control systems keeps the product compact in size.

ReVolt Technology description

Metal-air batteries consist of a negative electrode made from metals such as zinc (Zn), aluminium (Al), magnesium (Mg), iron (Fe), lithium (Li) and a positive electrode made from a porous structure with catalytic properties for the oxygen reaction. An alkaline electrolyte is used to maintain high ionic conductivity between the two electrodes. In order to prevent short circuit of the battery, a separator is placed between the anode and the cathode.

On discharging metal-air cells, oxygen from the atmosphere is converted to hydroxyl ions in the air electrode. The hydroxyl ions then migrate to the metal electrode, where they cause the metal contained in the electrode to oxidize. In particular, the desired reaction in the air electrode of a metal-air cell involves the reduction of oxygen, the consumption of electrons and the production of hydroxyl ions. The hydroxyl ions can migrate through the electrolyte towards the metal electrode, where oxidation of the metal may occur, forming oxides and liberating electrons. Charging of metal-air cells converts hydroxyl ions to oxygen in the air electrode, releasing electrons. On the metal electrode the metal oxides or ions are reduced to form the metal while electrons are consumed.

Development of the air electrode in general has been focused on the use in fuel cell applications. Therefore, studies of the oxygen reduction reaction dominate. The alkaline fuel cell (AFC) system shows high reaction rates and stability for oxygen reduction with the use of non-noble materials. The reaction takes place on finely dispersed catalysts with a high surface area for reaction. By careful control of the hydrophobicity and the pore size distribution, a stable three phase zone is established inside the electrode. Typically, air electrodes in AFC applications show stable behaviour. Such systems are operated at temperatures of 60-90 ^oC. At lower temperatures increased lifetime has been shown.

Before such electrodes can be used in secondary battery applications (rechargeable batteries) the electrodes have to be modified. Charging the battery requires air electrodes with additional high oxygen evolution rates. Bifunctional air electrodes showing high rate capability and stability for oxygen evolution must be developed. Stable reactions for oxygen reduction and oxygen evolution over several hundred charge/discharge cycles are required for secondary metal-air batteries.

Zinc (Zn) has been used in many batteries as the anode material. This is due to the high energy density of zinc and its chemical stability in the electrolyte. Zinc electrodes enable high current densities and a flat discharge curve. Battery systems such as the Nickel-Zinc battery, the Silver-Zinc battery, Zinc-Chloride battery, Zinc-Bromide battery the Zinc-Manganese battery etc. are well known. A zinc electrode can be made from a solid plate, pellets or powder zinc materials. If powder material is used, an organic gelling agent is often added to allow sufficient electrolyte penetration and to maintain particle to particle contact.

For secondary batteries with zinc as the anode active material, low cost and relatively high energy density can be obtained. This is offset by the short cycle life of the battery. The short cycle life is mainly due to the following:

- Dendrite formation during charging of the battery. Such dendrites penetrate the separator and cause a short circuit of the battery system.
- Shape changes of the electrode. This results in a loss of active surface area, contact inside the electrode or a local densification of the electrode.

Development of ReVolt's portable battery has been achieved by focusing on the areas of power, battery life, rechargeability and compact size. Some issues remain to be addressed prior to successful market introduction.

POWER

One consideration for development of a metal-air battery for portable electronics is ensuring that it can provide sufficient power. The power capacity of a system is limited by the reaction rates of the electrodes and the conductivity of the electrolyte.

ReVolt has developed high power electrodes. In combination with an electrolyte of high conductivity the ohmic voltage drop is minimized.

The air electrode

The oxygen reaction takes place within a thin flexible layer. Air diffuses into this layer through a network of hydrophobic channels. By capillary forces the electrolyte penetrates the structure. The liquid-gas interface established within the electrode creates a three phase reaction zone. High power is enabled by a stable high surface area reaction zone within the air electrode.

Figure 1 shows the polarisation sweep of ReVolt's air electrode. High current at a low voltage drop is shown. It should be noticed that currents as high as 200 mA/cm^2 are obtained before diffusion starts limiting the reaction rate at a temperature of 20 ^{o}C.

The result is obtained by choosing the correct materials and production methods. The use of a low-cost catalyst is of particular importance.

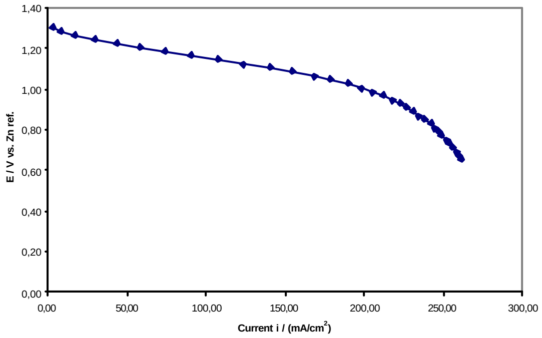

Figure 1: The rate of oxygen reduction in ReVolt's air electrode.

The zinc electrode

Zinc used as a battery anode is recognized as a good choice for high power battery applications. This is due to the flat discharge curve for zinc. ReVolt's zinc electrode is made from carefully selected powder materials.

Figure 2 shows the polarisation sweep of ReVolt's zinc electrode. A linear current – voltage curve with a slope of 0.88? cm^2 is given for a current of up to 200mA/cm^2.

The objective of the electrode is to maintain this flat discharge curve for electrodes that are stable over several hundred charge/discharge cycles.

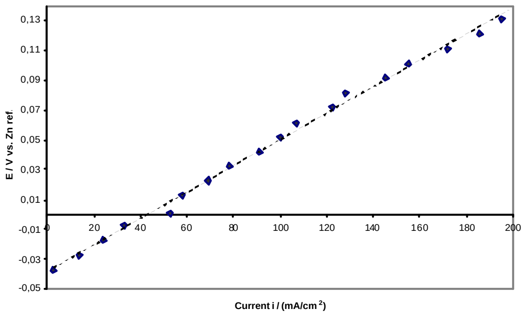

Figure 2: The rate of zinc oxidation in ReVolt's zinc electrode.

LIFETIME

Air electrode

High stability of the air electrode is crucial for use in rechargeable metal-air batteries. In order to make a stable air electrode the three-phase reaction zone should be stable for several thousand hours at high current densities. The degradation of the air electrode is related to the current density. At low currents and at open circuit potential, the electrode is stable. At high currents, radicals formed in the air electrode can alter the properties of the electrode, resulting in a loss of reaction rate and increase of cell resistance. The degradation mechanism is thus closely related to the current density and operating temperature.

Lifetime cycling tests at high current densities were performed to investigate any degradation. Figure 3 shows cycling data of ReVolt's air electrode. The figure shows high stability even after 100 charge/discharge cycles at high rate. The high stability of the air electrode is a result of the careful choice of materials. The catalyst is provided on a stable carrier and a pore former is added to give a porous structure with a high surface area for reaction.

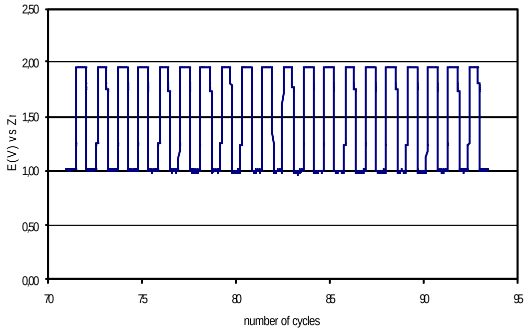

Figure 3: Charge/discharge cycling of the air electrode (100 cycles at 100 mA/cm^2 and 20 °C) of ReVolt's air electrode.

Zinc electrode

The total lifetime of the zinc electrode is given by the number of charge/discharge cycles available. The lifetime between charges is given by the energy density available from the zinc electrode.

Figure 4 shows the energy density of the zinc electrode as a function of time. The battery electrode shown in the figure was loaded with zinc giving a theoretical capacity of 4 Ah. As can be seen in the figure, a capacity of 2.8 Ah (70 percent of the theoretical capacity) was utilised.

To reduce the loss of capacity at open circuit (self discharge) requires the prevention of unwanted dissolution of metal. A method for accomplishing this has been developed. Alloying the metal with elements that give high overpotential for the hydrogen reaction and a careful selection of materials are implemented.

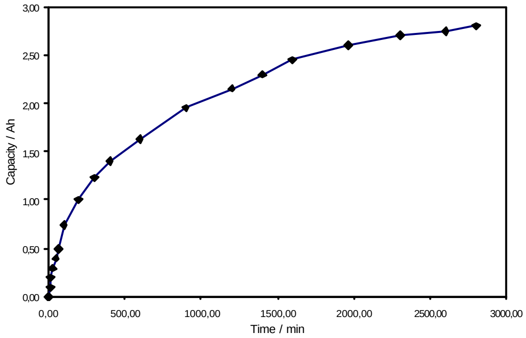

Figure 4: Capacity of ReVolt's zinc electrode.

Humidity management

The air electrode in a metal-air battery interacts with the environment by gas transport in and out of the air electrode. The hydrophobic backing layer prevents any liquid penetration. At low relative humidity and high temperature, water will evaporate resulting in a slow drying out of the battery.

ReVolt's approach to this challenge is modification of the electrolyte and the electrodes. A stable water balance is obtained even at high temperatures and dry ambient conditions. Figure 5 shows the comparison between Revolt's solution and a standard alkaline electrolyte. As can be seen even after several thousand hours in test no weight loss is observed due to water evaporation in ReVolt's modified system.

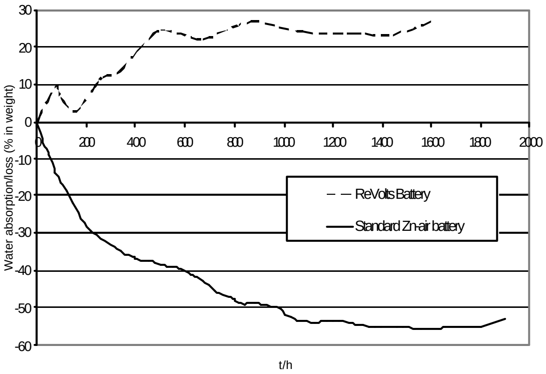

Figure 5: Comparison of water vapour loss in standard electrolyte and with ReVolt's new water management system.

RECHARGEABILITY

Air electrode

The use of bifunctional air electrodes gives many advantages to establish a compact rechargeable metal-air battery. In a bifunctional air electrode, both the oxygen reduction and oxygen evolution reactions occur. Previously, it has been show that high reaction rates of the oxygen reduction reaction are obtained with ReVolt's electrodes. High power and lifetime for the oxygen evolution reaction is also obtained.

Figure 6 shows the anodic polarisation of ReVolt's bifunctional air electrode. As can been seen from the figure, high rates of oxygen evolution are obtained at low overpotential. Oxygen evolution at a potential of less than 2 V is important in order to preserve the catalysts and porosity of the electrode. As shown in the figure, oxygen evolution rates of 200mA/cm^2 are obtained at potentials less that 2 V. This allows rapid charging of the metal-air battery without degradation of the air electrode.

Figure 7 shows anodic charge cycles for the air electrode. As can be seen from the figure, high stability of the oxygen evolution reaction is maintained after repeated charging (more than 100 cycles) at an oxygen evolution current density of 100-200 mA/cm^2.

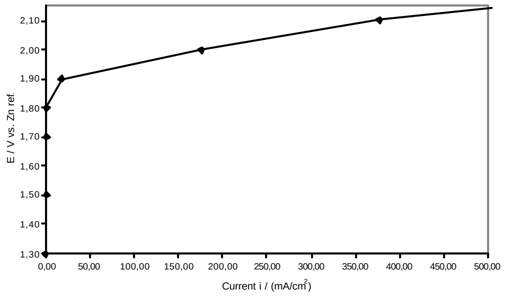

Figure 6: Oxygen evolution at ReVolt's air electrode.

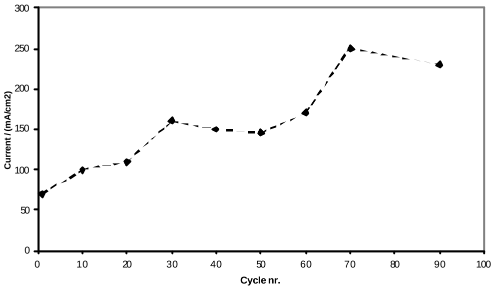

Figure 7: Oxygen evolution as a function of charge/discharge cycling of ReVolt's bifunctional air electrode

Zinc electrode

One critical part for enabling rechargeable metal-air batteries is the development of a rechargeable metal electrode. The electrode should not give unwanted dendrite growth, leading to short circuits in the battery or shape changes causing loss of capacity.

Figure 8 shows charge/discharge cycling of ReVolt's zinc electrode. As can be seen from the figure the charge/discharge process is remarkably stable with high rates for both charge and discharge. After 200 cycles with 5 percent of total capacity, no dendrites or loss of capacity were observed.

Figure 9 shows high capacity charge/discharge cycling of ReVolt's zinc electrode. The charge/discharge reaction proceeded up to about 50 percent of total capacity. A slight increase in capacity was observed with cycling. This is due to an increase in the available surface area during cycling. After 100 cycles the experiment was terminated. No dendrite formation was observed.

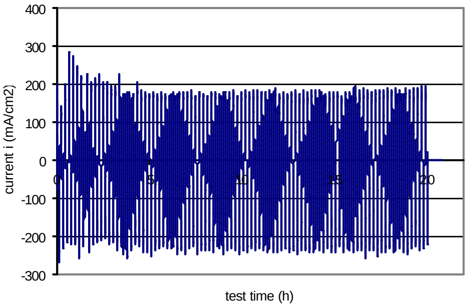

Figure 8: Charge/discharge cycling (100 cycles) of ReVolt's Zn electrode (potential range from -150 mV to +150 mV.)

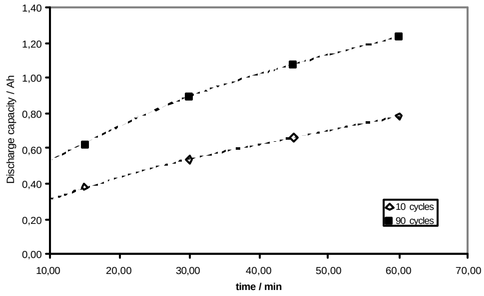

Figure 9: Discharge capacity after 10 and 90 charge/discharge cycles. The discharge lasted for one hour at constant potential of 150 mV vs. Zn.

Full cell

Figure 10 shows the charge / discharge behaviour of a full cell system. The battery was charged and discharged at 0.5 C for a 400 mAh cell. The discharge capacity was 97.5 % of the capacity on charge. The full cell verifies the stability shown by the electrodes.

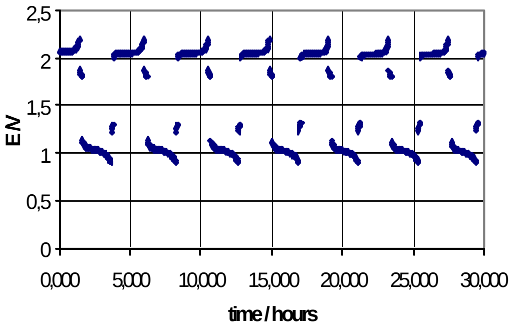

Figure 10: Charge / discharge of full cell. (0.5 C, discharge efficiency 97.5 %)

COMPACT SIZE

Introducing portable metal-air batteries in the consumer electronics market requires a compact battery configuration without peripherals such as cooling fans, temperature control systems or electrolyte circulation. ReVolt's metal-air battery provides a compact battery without any such peripherals. The high mobility and activity of oxygen in the battery enables air diffusion to give sufficient power.

Figure 11 shows the power and efficiency of ReVolt's battery. As can be seen from the figure, high power is obtained for the battery system.

Figure 12 shows prototypes used in testing the battery performance. The standard test prototype is a prismatic cell of a size similar to that used in mobile phones.

Figure 13 shows the discharge curve of one prototype battery. A discharge capacity of 7.16 Ah was obtained. The energy density of the system was estimated to be more than 1100 Wh/l (not including the excess frame volume).

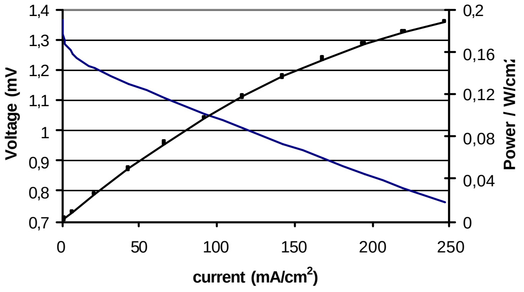

Figure 11: Power and efficiency of ReVolt's portable battery cell.

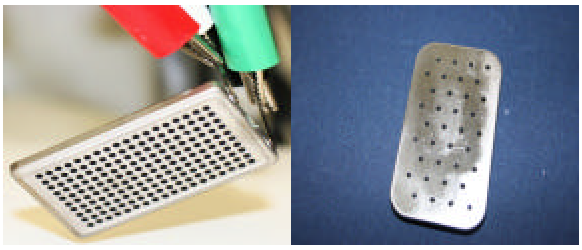

Figure 12: Prototype batteries.

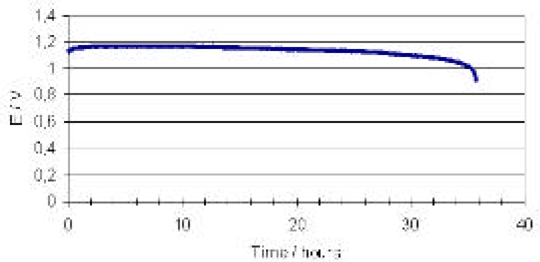

Figure 13: Discharge curve for one prototype battery (7.16 Ah). Estimated capacity for cell: 1140 Wh/l.