New Battery Possibilities for High-temperature Electronics

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Abstract

This paper covers a new type of batteries that allows the following possibilities for high-temperature applications, namely: (a) safety and full operational capability at temperatures up to 275 °C (527 °F); (b) possibility of battery recharging at high temperatures; (c) full operational capability under severe industrial conditions (vibration, shock); (d) environmental safety under transportation, storage, use and disposal; (e) safety under harsh conditions including emergency situations as a fire (this has been demonstrated with discharge tests of battery prototypes placed in a diesel fuel fire). Two technological generations of the battery prototypes have been designed, fabricated and tested over an operating temperature range of 4 °C (39 °F) to 275 °C (527 °F). The battery prototypes have been also tested under super-harsh conditions. The variety of form-factors is available for this type of batteries, including for their application in MWD/LWD tools and long-term power supply of monitoring systems in producing wells. Efforts are underway to develop the third generation of the batteries of sub-micron size (micro-batteries for microelements including high-temperature ones).

Key Words: Batteries, High temperatures, Safety, Rechargeable

Introduction

There is a growth of requirements to increase energy density and improve safety of batteries, including environmental safety. The main difficulty of the existing batteries is that the higher energy density is, the higher hazard risk becomes[1]. Battery safety at elevated and high temperatures is especially important because the existing batteries fail under these conditions and become fire-hazardous and highly explosive.

We develop the new concept and technology of safe batteries possessing high energy density for the commercialization at distinct markets. This new type of batteries provides new possibilities including previously unachievable ones, e.g. a safe high-temperature power supply. The safe batteries for high-temperature applications (SB-HTA) can be applicable for high-temperature electronics, microelectronics, high-temperature sensors, microsensors and other high-temperature devices equipped with the battery supply. SB-HTA can be applicable both for the existing high-temperature tools and technologies and for the future ones.

Concept and technology of safe batteries

New physical and technological concept for high temperature batteries is based on superionic conductors with nanostructured anionic disorder. Solid-state fluoride-ion galvanic heterostructures are the base of the battery (Figure 1)[2-3].

Solid-state Cathode (on the left); Solid-state Anode (on the right); Solid-state Electrolyte (in the middle)

Figure 1: Galvanic heterostructures

Distinctive features:

Batteries consist of ceramics based on solid superionic conductors and metal ceramics. There are no gas or liquid phases in the battery.

The stable solid-phase electrode reactions, taking place in the wide temperature range are realized in the batteries.

Superhigh ionic diffusion in solid phases and high rate of solid phase current generating process at electrodes are realized in the batteries.

New batteries have the following possibilities for high-temperature applications, described further in this paper:

Safety and full operability at high temperatures

Two technological generations of the battery prototypes have been designed and fabricated. The prototypes have been tested over an operating temperature range of 4 °C (39 °F) to 275 °C (527 °F) including the harsh environment tests and tests under emergency conditions. The results of the tests have shown the new possibilities of the battery-power supply for high-temperature applications, namely:

(a) Safety and full operability up to 275 °C (527 °F);

(b) Possibility of recharging at high temperatures;

(c) Full operability under severe industrial conditions (vibration, shock);

(d) Environmental safety under transportation, storage, use and disposal;

(e) Safety under harsh conditions including emergency situations such as a fire (this has been demonstrated with discharge tests of battery prototypes placed in a diesel fuel fire).

Some SB-HTA test results proving the above-listed possibilities:

Figure 2 shows discharge of the prototype of BS-HTV (3.7 V; 1 Ah). Discharge at 200°C (392 °F); Current - 0.15A; Power - 0.5 W.

Figures 3-5 show discharge of those battery prototypes with step change of the discharge current to determine power density available at different discharge temperatures.

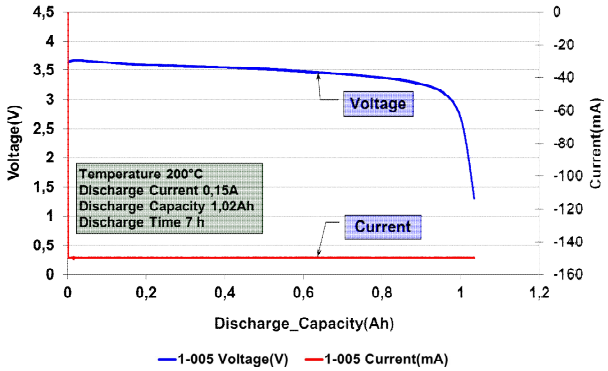

Figure 2: Discharge at 200°C (392 °F)

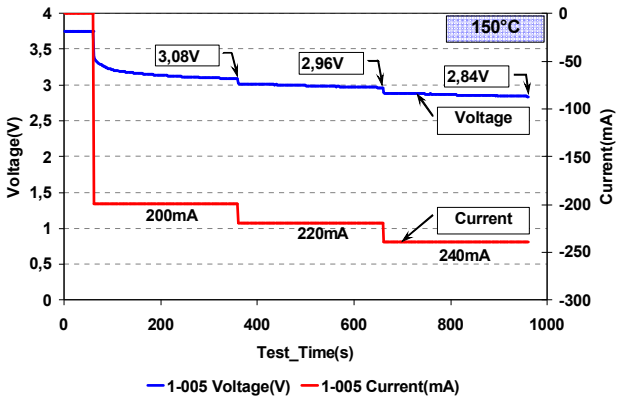

Figure 3: Discharge tests with the current stepping at 150 °C (302°F) Power - 0.65 W

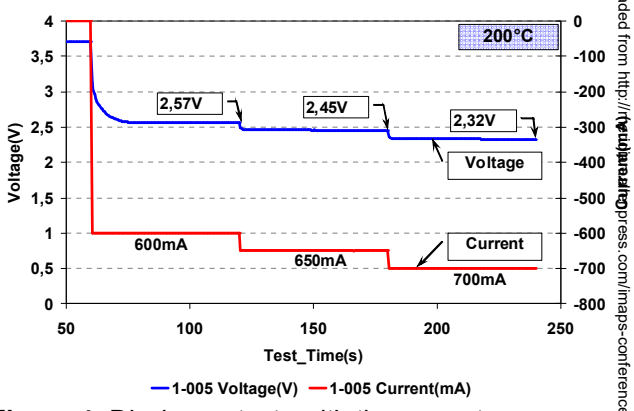

Figure 4: Discharge tests with the current stepping at 200 °C (392 °F) Power - 1.6 W

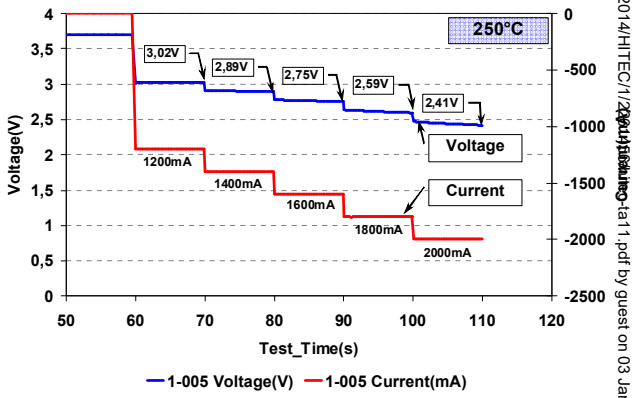

Figure 5: Discharge tests with the current stepping at 250 °C (482 °F) Power - 4.5 W

Tests that have been conducted, including tests illustrated here and results of additional tests indicate that:

All processes take place in solid phase at the discharge. High rate of solid-phase reactions in the galvanic heterostructures determines the availability of high discharge current.

Additionally, characteristics include:

- The discharge is stable;
- The batteries are safe during the discharge;

- In case of a short circuit the batteries are safe and can rapidly return to a normal mode;
- The high discharge power and safety are available at high temperatures;
- The higher temperature is, the more power is. The temperature vs. power dependence is described accurately by exponential functions (parametric predictability);
- The high-power and short pulses are available at the pulsed discharges.

Possibility of recharging at high temperatures

SB-HTA provide the possibility of battery recharging at high temperatures. The number of discharge/charge cycles can be large up to 2000 cycles according to the test results without the noticeable change in characteristics.

Recharging of batteries is available at different high temperatures up to 250 °C according to the test results.

Power and time of a charging cycle can be different and are determined by a specific high-temperature application.

As a mater of demonstration of recharging at high temperatures, Figure 6 shows charging/discharging cycles of a SB-HTV prototype at 150 °C (OCV 3.7V).

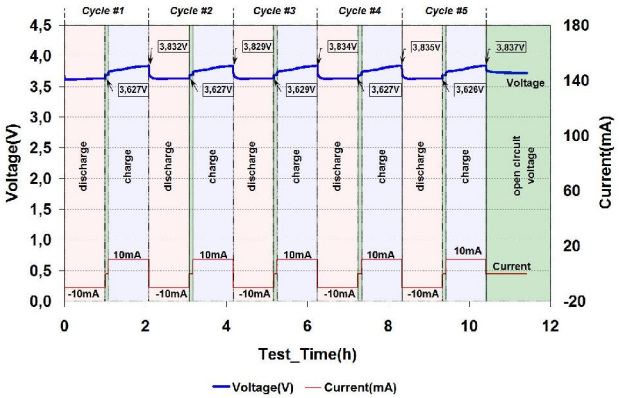

Figure 6: Discharge-Charge at 150 ^{0}C (302 °F)

Full operability under severe industrial conditions

Prototypes of SB-HTV ("D" size) have successfully passed tests in harsh industrial conditions. Tests were done by third parties and included:

- Battery tests at 200 ^{0}C (392 ^{0}F) for 2000 hours;
- Temperature cycling at -20 ^{0}C (-4 ^{0}F) …+200 ^{0}C (392 ^{0}F);
- Vibration at +200 ^{0}C (392 ^{0}F)
- Shock Test at Room temperature and +200 ^{0}C (392 ^{0}F);
- Short Circuit Test at +30 ^{0}C (86 ^{0}F).

SB-HTV technology showed itself as fully safe and operational under severe industrial conditions

Safety under harsh conditions

The new battery technology has been tested under the unique harsh high-temperature conditions:

"D" prototype of SB-HTA was placed in a diesel fuel fire. During the test the discharge and temperature of the battery were under the direct control.

In the end of the test the fire was put out with water (Note: it is absolutely forbidden for lithium batteries).

The test was captured on video.

The film allows seeing simultaneously the behaviour of the battery in the fire, the battery's temperature and the control of the battery's operability.

Some frames are presented here (Figures 7-11):

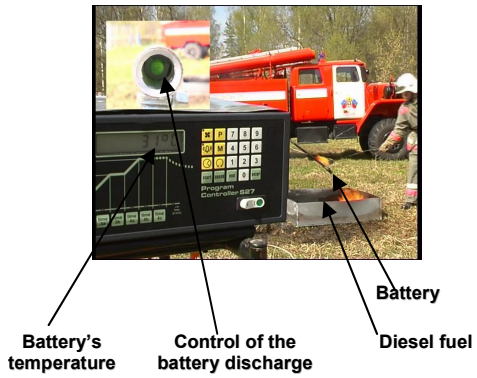

Figure 7: A fireman fires diesel fuel

Figure 8: Battery's temperature 258 ^{0}C (496 ^{0}F) Safety and full operational capability!

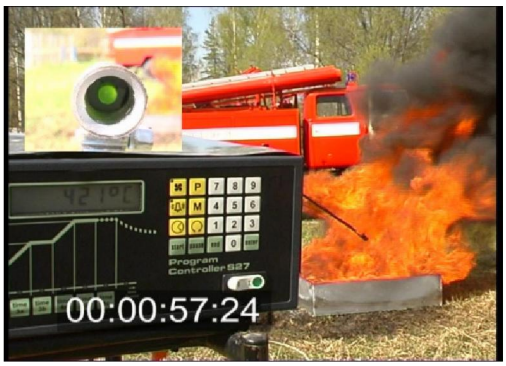

Figure 9: Battery's temperature 421 ^{0}C (790 ^{0}F) Safety and full operational capability!

Figure 10: Battery's temperature 653 ^{0}C (1207 ^{0}F); Safety and full operational capability!

Figure 11: Fire extinguishing; The battery under the fire and hot water vapors

The results of the tests demonstrate full Safety and full operational capability in fire;
The battery did not been even destroyed after such super-harsh test and demonstrated the complete environmental safety.

SB-HTA prototype: "D" size before the test - on the left; after the test – on the right (Figure 12)

Figure 12: SB-HTA prototype - discharge tests of battery prototypes placed in a diesel fuel fire

Safe batteries for high-temperature applications (SB-HTA) Shapes and Sizes
SB-HTA differ from the current cells considerably, including Lithium Thionyl Cloride ($Li/SOCl_2$) cells in terms of flexibility of size and shape parameters, namely:

Voltage of 3.7 V is not its firm parameter. For example, SB-HTA of "C" size can have voltage more than 100V;

The range of shapes and sizes is very flexible and depends on tool/technology requirements of high-temperature application.

SB-HTA can be made of different shapes and sizes:

- Like $Li/SOCl_2$ batteries, SB-HTA can be in the shape of cylinder;
- SB-HTA can have a rectangular shape;
- They can have other shapes that are optimal for the specific high-temperature applications;
- SB-HTA can be thin (thickness is about one millimeter or more);
- They can be ultrathin (thickness is about one micron or more).

SB-HTA: Cylindrical shape
(for MWD/LWD and other high-temperature oil-and-gas and geothermal applications in wells - Figure 13).

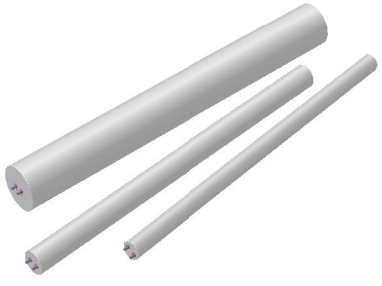

Figure 13: SB-HTA for wells

Based on possibilities, SB-HTA can be useful for the following oil-and-gas and geothermal applications:

High-temperature wells with temperature more than 180-200 ^{0}C.

(Note: If it is necessary to have very high energy and power at low and average temperatures, the SB-HTA might be used together with lithium batteries. In doing so, lithium batteries will provide energy at low and average temperatures and the SB-HTA - at high ones.)

New technologies based on the batteries, that operate for a long time at high temperatures in producing wells (months, years).

(Battery-power supply of monitoring systems, data-transmission systems, control systems for the actuating and anti-damage devices , etc.)

New technologies based on the SB-HTA that can be recharged by means of a generator inside the wells.

(Power backup under cutoff of a generator; the power supply with the enhanced power (in comparison with supply by generators), etc.)

The range of applications can be extended due to the future expected enhancement of the battery's possibilities.

Small and very small sizes

The safe batteries for high-temperature applications (SB-HTA) are available in small and very small sizes

The technology allows manufacturing of the safe submillimeter batteries for high-temperature applications.

A submillimeter prototype for high-temperature applications is presented in the photo. (Figure 14; beside it the usual paper clip is presented)

Figure 14: Submillimeter prototype 3.7 V; 25 mAh; Size: Ø 21.5 mm; thickness - 1.1 mm; Safety and fully operability up to 275 °C (527 °F); possibility of recharging at high temperatures.

The new concept of the safe high-power battery systems has a high development potential, namely:

- Increase of energy density specific characteristics [Wh/kg, Wh/l];
- Broadening of operating temperature range;
- Technological development, including submicron size

We have obtained the positive results in the development of the third technological generation of the SB-HTA with the thickness of the solid state electrolyte of about 0.3μm

This allows developing micro-batteries with the total thickness of 1 to few micron.

Micro-batteries can provide new battery possibilities for high-temperature microelectronic and micromechanical elements, micro-sensors and other micro-devices.

SUMMARY

New type of batteries provides new possibilities including previously unachievable ones, e.g. a safe high-temperature power supply.

The safe rechargeable batteries for high-temperature applications (SB-HTA) can extend the field of applications for high-temperature electronics equipped with battery-power supply, and open new ones.

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