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From RT-hydride Hydrolium®/H2Tank2Go® to B4S-SM/MM reactive hydride composite $LiBH_4$+MgH_2 made by HKP/powder metallurgy process

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***Abstract*— In order to secure the world's energy demands of tomorrow, the current dependency on fossil fuels will not be sustainable for much longer. To compensate a growing population and world economy together with depleting resources and increasing pollution, the answer can only be found in clean, renewable energies like wind- and solar power. As an energy-storage-medium, hydrogen can play a key factor in the future's energy-economy. Not only is it able to store the surplus-energy from wind and solar, it can also provide an alternative fuel for "zero-emission"- electric vehicles. Hydrogen is basically available everywhere on the planet (electrolysis of water) and therefore a prime candidate to become the "fuel of the future". Apart from the wide range of different areas in research and development, hydrogen technologies play a major part at Zoz in Germany.**

Keywords – reactive hydrogen composite; hydrogen storage; Simoloyer®; high capacity; boron hydride

I. Introduction

The "public" state of the art is described by battery-electrified vehicles at low range and fuel-cell electrified vehicles with tanks storing hydrogen at high pressure of about 700 bar. Such tanks have to be designed under high technical efforts with respect to the demands on materials and sealing. The corresponding refueling stations are complex, too and not at all available all over the country. Next to high cost for high pressure generation of H_2, the high pressure on board also does cause uncertainties with the costumer which both adds to limit a wide application of hydrogen-driven vehicles. High capacity solid state storage of hydrogen at low pressure can offer a technical and in the future might offer an economic solution in here.

II. Reactive Hydride Composites

Numerous hydrogen storage materials for are known. Hence the interaction of temperature and pressure during charging and discharging of the hydrides is of high importance, as well as the stability of the storage materials. Mg-based high temperature hydrides can store up to 6.5 wt.-% H_2 at a temperature >230°C. Solid-state storage systems with low temperature hydrides are based on binary and ternary transition metal hydrides such as TiH_2, $LaNi_5H_6$ as AB_2- and AB_5-alloys. However those provide a low gravimetric storage capacity up to 2.5 wt.-% at maximum [1].
Hydrides for moderate temperatures like alanates, e. g. $NaAlH_4$ offer a temperature-depending storage capacity which is, e. g. at 80°C about 2.5 wt.-% H_2 doubling at 120°C [2].
Important research is undertaken on reactive hydride composites (RHC) particularly the complex metal hydride system from lithium borohydride and magnesium hydride [5, 6] which are expected to provide a very high H_2-storage capacity (Eq. 1).

$$2\,LiBH_4 + MgH_2 \rightleftharpoons 2\,LiH + MgB_2 + 4\,H_2\uparrow \qquad (1)$$

Within the framework of the EU-project BOR4STORE (FCH JU grant 303428), synthesis and application of boron hydride based reactive hydrogen composite (RHC) - complexes as storage material with a gravimetric storage capacity up to 18 wt.-% have been developed [3, 4]. The EU- project ECOSTORE (Marie Curie ITN grant 607040) on the objective of knowledge dissemination on metal hydride storage materials, about synthesis, application and ecological and economical benefits is still ongoing [7]. The aim of these projects is the extensive establishment of hydrogen-driven mobility.

III. H2TANK2GO®

H2Tank2Go® represents the "click'n-go" Hydrogen-tank cartridge system containing rechargeable nanostructured RT-MH Hydrolium® that is developed for a clean, reliable, fast, mass-capable and cost-effective solid state hydrogen storage future utilizing given infrastructures such as vending machines, home-depot and home delivery. The H_2-capacity of the <1l tanks is >50g operating at <10bar at a lifetime >20years. Parameters of the H2Tank2Go®-system are given in Table 1.

Table 1: technical parameters H2Tank2Go®

H_2-capacity	50 g guaranteed; future target 100 g
weight	4,2 kg
length	330 mm
diameter	70 mm
operating pressure	< 10 bar
burst pressure	ca. 80 bar
material valve	brass
material vessel	stainless steel
metal hydride material	Hydrolium®
operating temperature	0 – 80 °C
storage capacity	ca. 1.8 wt.-%
charging pressure	15 bar
lifetime	> 20 years

Fig. 1: H2Tank2Go® loaded with metal hydride powder (Hydrolium®) served at a vending machine

IV. H_2-TANK SYSTEM B4S-SM

Research and development activities as part of the EU-project BOR4STORE resulted in the single-module tank system B4S-SM (Fig. 2) and in the multi-module tank system B4S-MM (Fig. 3) based on novel high capacity boron RHC materials for specific fuel cell applications, e.g. SOFC.

Fig. 2: single-module tank system B4S-SM

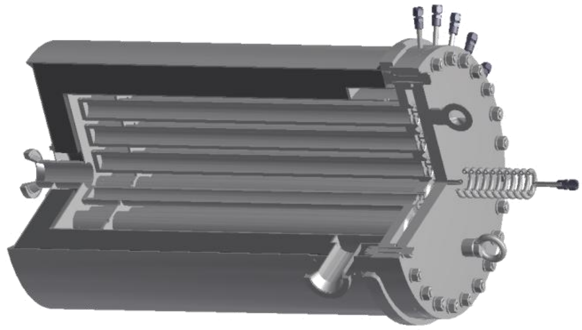

Fig. 3: multi-module tank system B4S-MM

B4S-tanks represent the world-wide first semi-commercial borohydride solid-state storage systems based on complex metal hydride ($LiBH_4$ & MgH_2) and have been introduced in June 2016 by Zoz and Helmholtz-Centre Geesthacht (HZG) in Germany. Resulting from the EU-project BOR4STORE, RHC are synthesized under extremely closed and clean condition in a Simoloyer® CM100-s2 in auto-batch processing at the HZG - Hydrogen Technology Centre at ZTC (Zoz Technology Center) at Olpe/Germany (Fig. 4).

Fig. 4. Simoloyer® CM100-s2, auto-batch processing

B4S-SM achieves a gravimetric H_2-density of almost 10 wt.-% fully reversible in the H_2-storage powder where the theoretical value is even higher at 18.3 wt.-%. This tank system received TÜV-approval in March 2016.

Table 2: technical parameters B4S-SM

H_2-capacity	40-50g
volume	712 cm³
weight	25,5 kg

The B4S-SM tank system contains novel boron hydride based materials and composites with accelerated reaction kinetics and appropriate reaction temperatures to supply a SOFC. The capacity of the system is > 8 wt.% and 80 kg H_2/m^3. It enhances the cycling stability of the materials to several 1000 cycles and provides electrical heating, electrical control and surveillance. The operating parameters are shown in Table 3.

Table 3: Operating parameters B4S-SM

pressure	3-100 bar
temperature	Max. 650°C
charging pressure	50-60 bar
design pressure	325 bar

Fig. 5. H_2-tank system B4S-SM

V. Conclusion

Hydrogen-driven mobility is most favorable due to the fact that fossil fuel driven vehicles will be presumably phased out of the market before the end of the century and solely battery driven vehicles cannot provide the needed energy density especially for long range efforts. Therefore RHC with higher storage capacity and novel tank systems have been developed which leads to a new generation of hydrogen-storage systems. There is still research going on taking cost-effective fuel cells and new carrier materials for hydrogen storage composites into account. In the near future cost-effective and safer H_2-driven mobility will be achieved.

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