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Solid State Hydrogen Storage: A Review on Recent Progress and Applications

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Abstract- **Recently, human beings completely depend on non-renewable resources such as natural gas, coal, and oil to meet their energy needs. Metal hydride has long-term stability and low hydrogen pressure, and is a safe alternative to hydrogen storage. In addition, they have a high volumetric energy density about 60% more than liquid hydrogen. For decades, the behavior of hydrogen in metals has attracted the attention of the scientific community, and it is interesting in both point of view from the perspective of basic research and the perspective of technology. Metal hydrogen systems are used in energy storage systems in various applications. The hydrogen solubility of the M-H system is strongly affected by the morphology and microstructure, as well as the stress between regions of different hydrogen concentration.**

Index Terms- **Hydrogen Energy, Metal hydride, Solid State Hydrogen Storage.**

I. INTRODUCTION

Hydrogen is considered a clean and sustainable energy carrier, which can eventually replace non-renewable fossil fuels, so it can solve the latter's availability, environmental and health problems [1, 2]. One of the greatest advantages of hydrogen as an energy vector is its high energy density by weight, which is the calorific value per unit of weight. In the future, hydrogen will become a complete replacement for the important fossil fuel. One of the most attractive characteristics of hydrogen as a fuel is that its main raw material is water. Therefore, it can be generated from water by solar energy or any other form of energy, and can be described as a primary energy source, even if it does not exist in nature. The contamination-free aspect of hydrogen is of particular importance to most of the world [3, 4].

Hydrogen is an ideal energy storage method for transporting and converting energy into a comprehensive clean energy concept. Hydrogen fuel can be stored in a gaseous, liquid, or solid state, and many efforts have been made to develop a hydrogen storage system that is safe, cost-effective, environmentally friendly, and most importantly, has high energy density. Among the three hydrogen storage technologies, storing hydrogen in solid compounds appears to be the most feasible solution because it is a safer and more convenient method than high pressure compression and liquefaction technologies.

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In this sense, metal hydrides are potential compounds for solid state hydrogen storage. However, due to the very low boiling point of hydrogen (20.4 K per atom) and the low gas density (90 g/m^3), suitable storage facilities for stationary and mobile applications are complicated. One of the remarkable characteristics of hydrogen in metals is its great fluidity. At room temperature, its diffusion coefficient can reach up to 10^5 cm^2/S, that is, this value is almost equivalent to diffusion in liquid. The reason for this high mobility is that hydrogen atoms occupy interstitial positions in the host lattice [5]. Among metal hydrides, magnesium hydride is considered one of the most attractive hydrogen storage materials, mainly due to its high storage capacity of (7.6% by weight in MgH_2), light weight and low cost [6, 7]. However, due to its high thermodynamic stability (H = 75 kJ/mol), high hydrogen desorption temperature (above 400°C), and relatively poor hydrogen absorption / desorption kinetics at temperatures below 350°C, Recently, ball mills and mechanical alloys have been developed to process Nano crystalline magnesium (~ 10 nm) in a hydrogen environment to achieve special advantages, such as improving the thermodynamic and kinetic properties of hydrogenation [8].

II. HYDRIDING KINEMATICS OF METALS

There are two possible ways of hydriding the metals, direct dissociation, chemical adsorption, and electrochemical decomposition of water. These reactions are as [9].

$$M + \frac{x}{2}H_2 \leftrightarrow MH_x$$

and

$$M + \frac{x}{2}H_2O + \frac{x}{2}e^- \leftrightarrow MH_x + \frac{x}{2}OH^-$$

where M represents the metal. In electrochemical decomposition, a catalyst, such as palladium, is necessary to decompose water. The schematic diagram of hydrogen chemisorption is shown in Fig. 1 and it shows the molecular hydrogen reaches a shallow minimum potential near the surface, while atomic hydrogen almost reaches a deeper minimum near the surface. In the metal lattice, hydrogen has a periodic minimum potential at the interstitial positions of the metal lattice. This behavior is explained below and pictured in Fig. 2. When hydrogen molecules approach the metal surface, weak van der Waals forces begin to act on it, bringing it closer. The molecule reaches the potential well Ep at a distance of Zp, and a very large force is required to bring it close to the surface as a molecule. However, the chemisorption energy exceeds the dissociation energy of hydrogen molecules. As a result, hydrogen molecules dissociate, and individual hydrogen atoms are attracted to the surface by chemical adsorption and reach the potential ECH trap. From this point on, sometimes even the thermal energy at room temperature is enough to increase the vibration amplitude of hydrogen atoms that can reach and enter the metal surface [10].

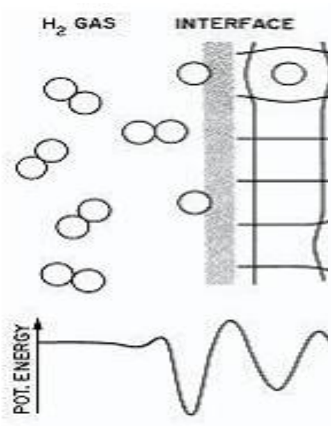

Fig. 1 Schematic diagram of hydrogen chemisorptions on metal [11]

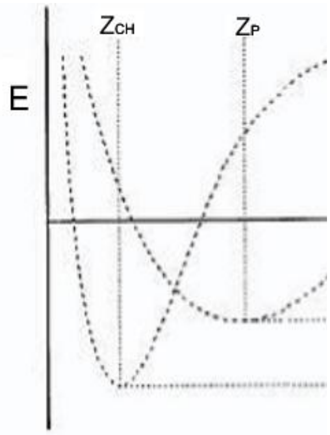

Fig. 2 Potential wells of molecular and atomic hydrogen [12]

III. APPLICATIONS OF METAL HYDRIDE DEVICES

A. Hydrogen storage systems for portable applications:

The concept of "hydrogen economy" requires electrical appliances that require electricity and/or energy to be powered by fuel cells that consume hydrogen as much as possible. This requires hydrogen-powered electric cars, trucks and generators, and even mobile phones, laptops and cameras. The scale of these applications is so large that it is almost impossible to use only one system for all applications. The hydrogen consumption per ton of megawatt generators is different from the hydrogen storage requirements needed to power mobile phones that consume only a few watts. Mobile hydrogen storage has been widely analyzed not only in the scientific community, but also at the political and industrial level in countries with far-distant interests such as the United States, Iceland, or Germany. In the first, a comprehensive set of requirements has been developed to translate research into practical systems and possibly sell to clients across the country [13, 14].

B. Metal hydrides for thermal storage:

The devices based on Mgthin films have the potential to serve as different reflective coatings. Recently, it has been reported by comparing the state of metal Mg_2Ni and black $Mg_2NiH_{0.8}$ and explained that these materials have twice the light absorption contrast in the solar range. Since this material has an emissivity of less than 15% for black bodies at 100 °C, black bodies are an interesting heat sink. There is a need for such variable reflection metal hydride coatings (VAREM), especially for combined photovoltaic cell/solar collector installations. Variable reflection metal hydrideis inserted between the photovoltaic cell and the solar collector. When the heat load of the system becomes too high, Variable Reflective Metal Hydride also benefits the heat collection walls in buildings: These so-called Trombewalls allow the solar season to be used optically at all times of the day. [13, 14].

C. Switchable mirrors as indicator layers:

Hydrogen transport can be carried out through thin-film metal hydride systems, because thin-film metal hydrides cannot be reduced to higher concentrations in the form of energy and also provide us fact charging-discharging rate of hydrogenation. But the bulk hydrogen system is reduced to a high-power hydrogen concentration. Though, understanding and manipulating of hydrogen transport through the thin film is important for the control and optimization of coatings and thin film devices, such as hydrogen detectors, switchable metal hydride objectives or tunable magnetic elements. The fact that switchable mirror films have optical properties that are highly dependent on hydrogen concentration provides the possibility of using them as a two-dimensional indicator of hydrogen concentration [13, 14].

D.Smart windows:

To reduce the energy consumption in buildings and cars, the smart coatings can play an important role. In the United States, approximately 30% of primary energy consumption is used for heating / cooling / lighting of residential and office buildings. Until now, various active and passive window coverings have been proposed. In general one would like to regulate the solar power input, while maintaining visibility. Therefore, the optical characteristics of the visible light range must be different from the optical characteristics of the long wavelength range of the solar spectrum. To minimize heat input while maintaining external visibility, a window reflectance light between 0.5-1.65 eV can be used. This will significantly reduce the cooling requirements of the building. The fact that switchable metal hydrides can block incident radiation throughout the solar spectrum makes them interesting for use in cars, that is, to reduce the thermal load of parked cars [13, 14].

E..Fiber optic hydrogen sensors:

Recently, most of the commercial used hydrogen sensors are based on electrical measurements at the sensing point. This may be undesirable in a potentially expensive and explosive environment. These drawbacks can be avoided by using an optical detector, in which the end of the optical fiber is covered with a hydrogen sensitive layer. During the hydrogen absorption process, the induced changes in the optical properties of this layer are optically detected at the other end of the optical fiber. Compared with other hydrogen sensors, fiber optic sensors have the advantages of being simple but very sensitive, low-priced, insensitive to electromagnetic noise, explosion-proof, and allowing multiple detections using a central detector. They are low cost and more resistant to corrosion than standard wires [13, 14].

IV. SUMMARY

The admiration of hydrogen fuel has a thoughtful impact on the expected transition from fossil fuel based systems to clean energy systems. This seriously reduces greenhouse gas emissions to improve the environment and climate change, and uses inexhaustible fuel sources to meet energy needs and alleviate the energy crisis caused by the depletion of fossil fuels. As people's awareness of climate change and new intermittent renewable energy sources increases, hydrogen storage may become the frontier of energy storage solutions. In recent years, new types of intermetallic hydrides with various compositions are being investigated and studied. This makes it possible to expand the range of metal hydrides used for hydrogen storage. Metal hydrides are promising candidates for many stationary and mobile hydrogen storage applications.

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