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2011 Gaston Planté Medal acceptance speech

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Thank you very much, Professor Pavlov and Mr. President, for your very kind introduction. And may I express my sincerest thanks to the Gaston Planté Medal Committee for giving me this honour.

In the limited time available to me, I would like to say a few words about the evolution of lead-acid battery technology in automobiles.

The automobile from 1945 to 1960 required only a 6-V lead-acid battery simply to provide power for starting and to supply energy for lighting and ignition. The failure of the battery at that time is mainly due to the shrinkage of negative-plate material. Unlike the earlier automobiles, the present cars require a 12-V battery, not only to provide power and energy for the simple starting, lighting and ignition, but also for the increasing electronic control and devices in the car, such as electronic automatic climate control, sound/video and navigation systems, powered windows/sunroof electric seats, antilock brake, electronically controlled suspension and traction controlled system, etc. More importantly, for comfort purposes, the passenger compartment becomes larger and consequently, the engine compartment becomes smaller. This, in turn, will restrict the air circulation in the engine compartment and cause the temperature increase in the hood. Under such high-temperature environment, the service life of the battery becomes shorter and the failure changes from the shrinkage of negative-plate material to mainly the grid corrosion, positive-material shedding and undercharge. The hybridization of automobiles, namely hybrid-electric vehicles (HEVs), started from late 1990 with the introduction of the first mild HEV, Toyota Crown in 2001. The hybrid electric vehicles require a single 12-V battery in the micro HEV to 288-V battery pack in the full HEV to provide power and energy for idling start/stop in micro HEV and for further power assist and to receive power from regenerative braking in mild, medium HEVs and an additional pure electric vehicle driving range in full HEV. All these HEVs require the battery operated at high rate discharge-charge and under partial state-of-charge (SoC) condition. Under such operational conditions, the lead-acid battery fails prematurely because of negative plate. Nevertheless, it is not the material shrinkage, but the sulfation of the negative plate.

In August 2001, CSIRO had a joint project with the ALABC to develop a small pulsed-current generation device used for battery in the mild HEV. In this project, we subjected the lead-acid batteries to a 42-V profile to simulate the driving condition of mild HEV. Under such testing profile, it was found that the battery failed prematurely owing to the sulfation of the negative plates. The plates suffered from a progressive built-up of lead sulfate on the surface and this lead sulfate layer was difficult to recharge completely as shown in Fig. 1. Consequently, the mechanism of lead sulfate accumulation on the surface of the negative plate was developed.

During high rate discharge, the lead sulfate forms rapidly either in the interior or on the surface of the plate, but the reaction in the interior of the plate will soon slow down and/or stop (Fig. 1). This is because the diffusion rate of hydrogen sulfate ion from the bulk of the solution cannot catch up with the rapid consumption rate in the interior of the plate. On the other hand, the formation of lead sulfate on the plate surface still proceeds. This will reduces the surface area of the plate and further hinder the diffusion of hydrogen sulfate ion into the plate interior as the lead sulfate layer is a semi permeable membrane to the movement of the hydrogen sulfate. During subsequent charging, the current passes from the grid member to the surrounding material (Fig. 2). Since the charging current is high, the potential of the negative plate increases rapidly to such an extent that, given the lower level of the lead sulfate in the plate interior, the hydrogen gassing will occur before the current reaching the lead sulfate layer. Thus, complete conversion of lead sulfate cannot be achieved. With such repetitive action of high-rate discharge and charge, the lead sulfate will accumulate on the surface of the negative plates and, eventually, the battery cannot provide sufficient power for engine cranking.

In order to address this sulfation problem, CSIRO has invented the UltraBattery in 2003 and later cooperated with Furukawa Battery Co. Ltd., Japan and East Penn Manufacturing Co. Ltd., USA to further develop this technology into products. The UltraBattery is the hybrid energy storage device, which combines the lead-acid cell and the asymmetric lead-carbon supercapacitor into a single

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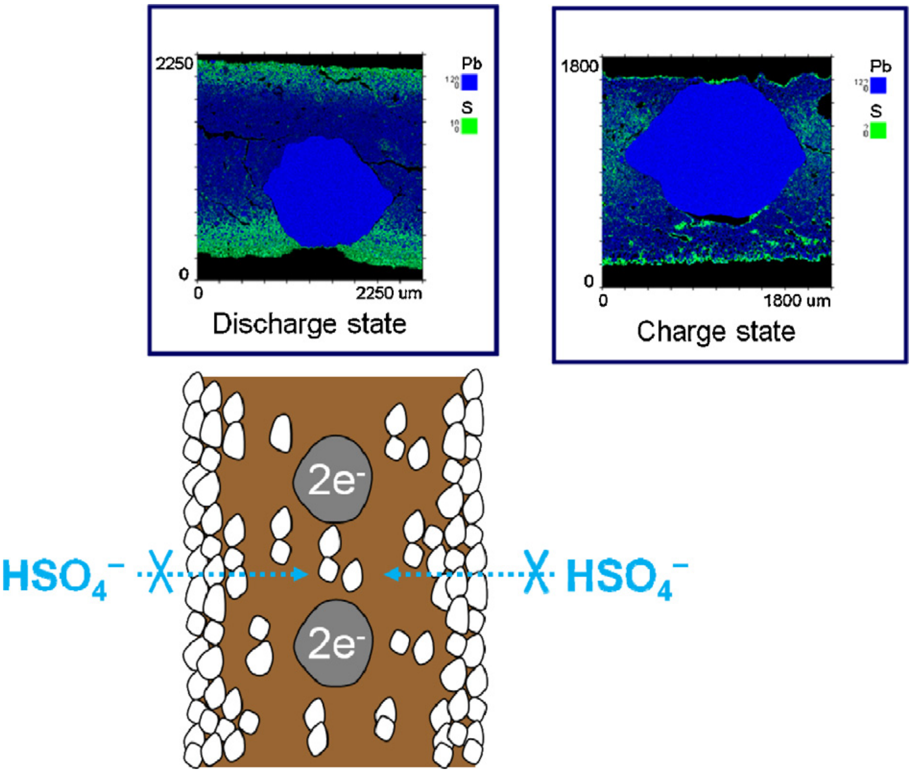

Fig. 1. Schematic diagram showing the development of lead sulfate during high-rate discharge.

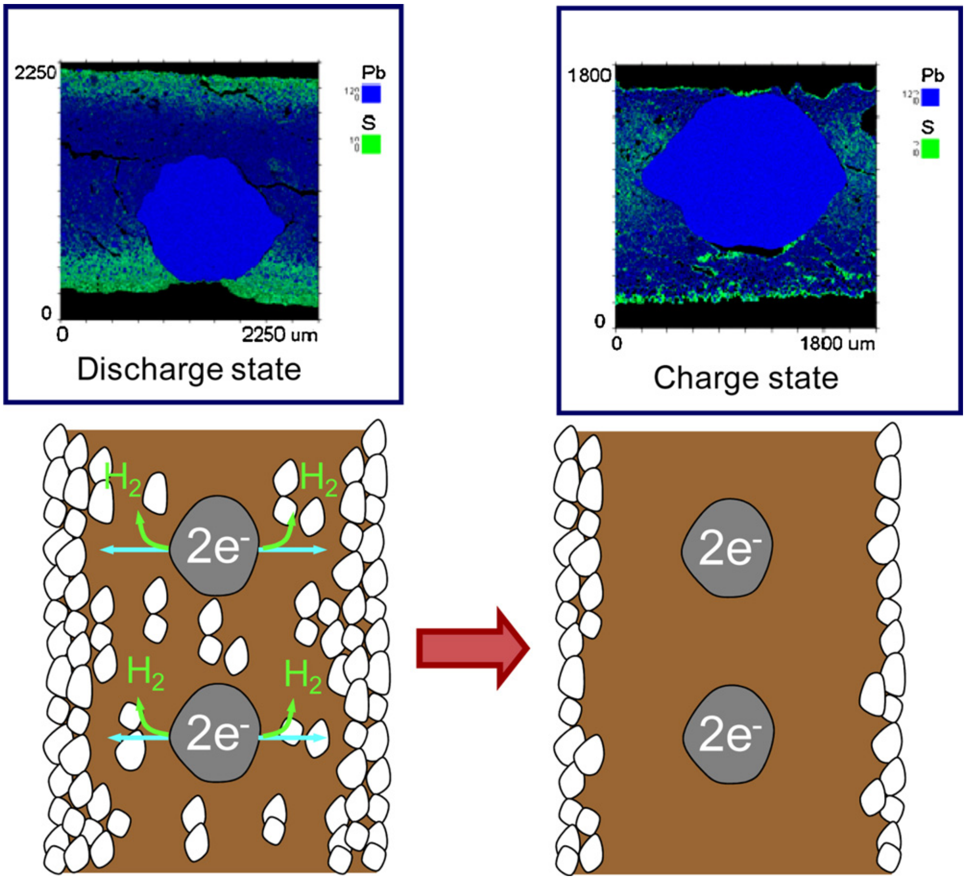

Fig. 2. Schematic diagram showing the uncompleted conversion of lead sulfate during high-rate charge.

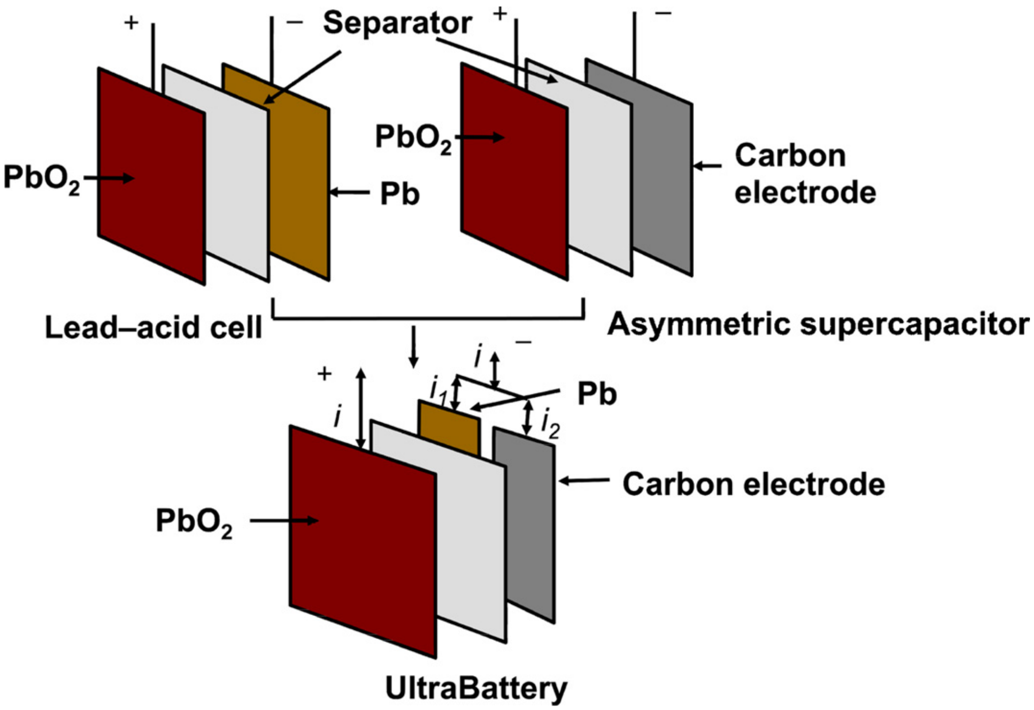

Fig. 3. Configuration of UltraBattery.

unit cell by connecting the capacitor electrode and the lead negative electrode in parallel (Fig. 3). Both electrodes now share the same lead-acid positive plate. With this design, the capacitor electrode can act as a buffer to share the discharge and charge currents with the lead-acid negative plate and thus prevent it being discharged and charged at the full rates required by the HEV duty. The capacitor electrode can also facilitate the movement of hydrogen ion and hydrogen sulfate ion in and out the negative plate during discharge and charge under high rates. Therefore, the UltraBattery has a better charge acceptance and can prevent or prolong the formation of sulfation layer on the surface of the negative plate. In 2006–2007, The UltraBatteries had been subjected to field trial in a Honda Insight medium HEV through the ALABC project DP 1.1 (Fig. 4). *The UltraBattery pack have successfully achieved over 160 000 km, without conditioning charging and are comparable to Ni-MH pack in terms of drivability, durability, fuel economy, CO_2 emission, but with greatly reduced cost.* After that, the Honda Insight has done another 40 000 km, with a total of 200 000 km and now is used as an exhibition car in the Furukawa Battery R&D center.

At present, several projects, which are conducted in parallel between the ALABC and the Furukawa Battery on the field trial of UltraBattery:

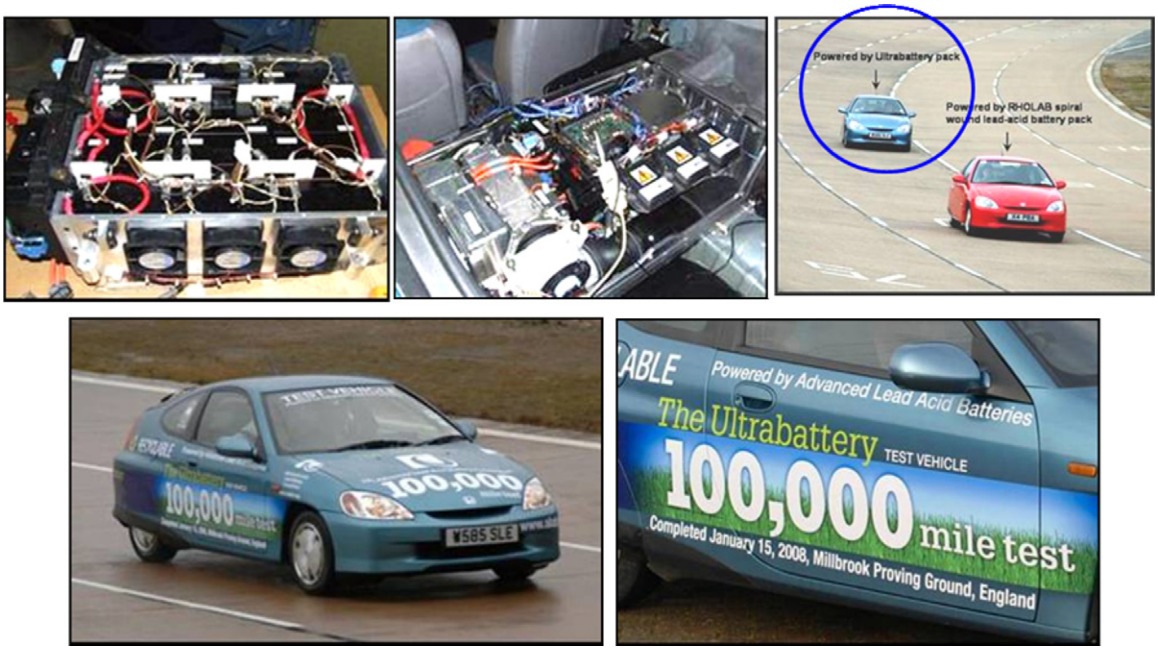

Fig. 4. Field trial of UltraBattery in the Honda Insight HEV.

SUZUKI "SWIFT" with Battery Sensor Alternator Control

Data Recorder with Battery Sensor Developed by the Furukawa Electric

Fig. 5. SUZUKI micro HEV.

(i) Don Karnar from ECOtality is currently conducting the field trial of the UltraBattery pack in the Honda Civic medium HEV.
(ii) Furukawa Battery is also conducting several field trials of flooded-electrolyte UltraBattery in the SUZUKI micro HEV and in the idling start/stop Taxis.

In addition to automotive applications, the UltraBattery is also used for stationary applications, such as for wind/solar smoothing and regulation service. East Penn Manufacturing is going to install 7 MWh of UltraBatteries by the end of 2011:

(i) Wind smoothing, 1 MWh, Hampton wind farm, NSW, Australia.
(ii) Solar smoothing, 1 MWh, NM, USA.
(iii) Regulation Service, 5 MWh, PA, USA.

In the following text, the field trial of flooded UltraBatteries in the SUZUKI HEV and in the idling start/stop taxis will be addressed. Fig. 5 shows the SUZUKI micro HEV with battery sensor alternator control. The data recorder with battery sensor is made from Furukawa Electric Co. Ltd., the mother company of Furukawa Battery. The changes in voltage, current and SoC of the standard battery during driving of the SUZUKI micro HEV are shown in Fig. 6. The top-of-charge voltage of the alternator is controlled at 14 V. It takes over 20 000 s or 5 h and 34 min to bring the SoC of standard battery from 85% to around 98%. On the other hand, the state-of-charge of UltraBattery in the same SUZUKI micro HEV increases from 89% to 100% SoC just within 7000 s or 1 h and 57 min after driving (Fig. 7). Furthermore, during traffic jam, the SoC of the UltraBattery drops to 97%, but recovers quickly to 100% within 450 s after traffic is clear. This indicates clearly that the charge acceptance of UltraBattery is superior than that of the standard battery.

The under-hood view of an idling start/stop (ISS) taxi is shown in Fig. 8. An InGEN data recorder from the Midtronic, USA was used to record the data during driving. Fig. 9 shows the comparison of cumulative charge and the cumulative number of engine re-starting between an idling start/stop (ISS) taxi and a conventional taxi during operating in Tokyo. Obviously, after 140-h operating, the number of engine re-starting in the ISS taxi is much greater than that in the conventional taxi, namely, 686 times compared with 96 times. On the other hand, the cumulative charge of the ISS

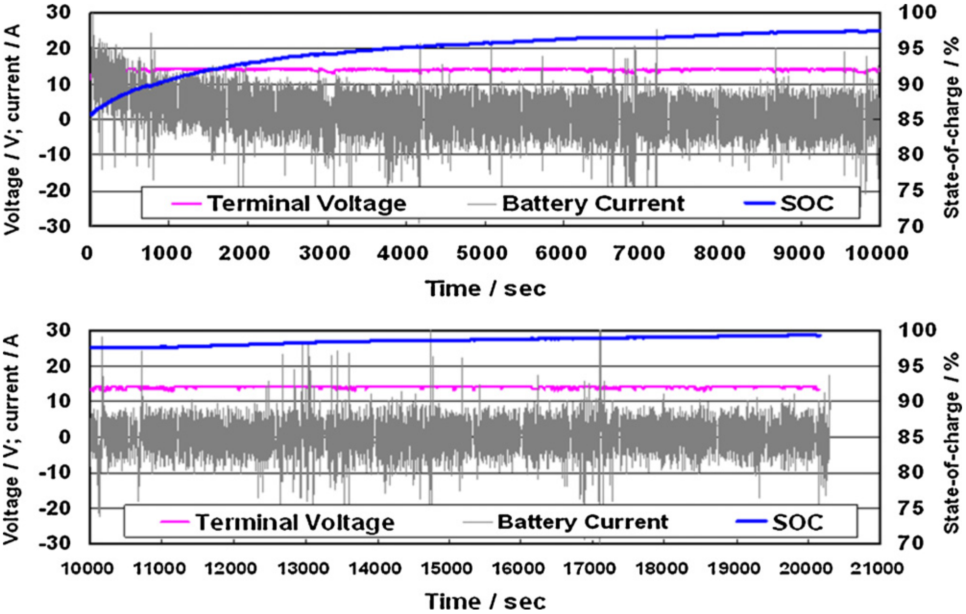

Fig. 6. Changes in voltage, current and state-of-charge of the conventional battery during driving; alternator output voltage controlled at 14.0 V.

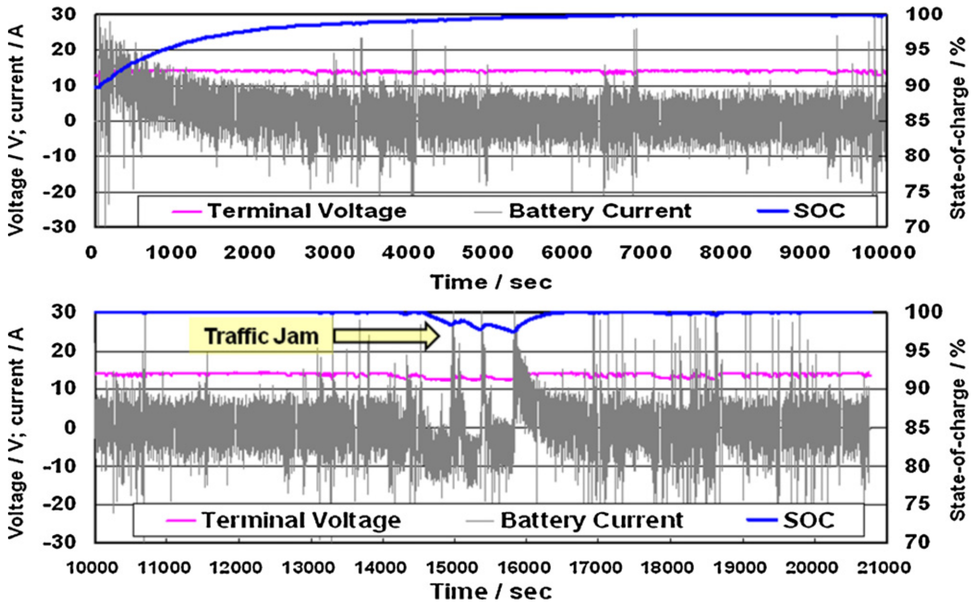

Fig. 7. Changes in voltage, current and state-of-charge of the UltraBattery during driving; alternator output voltage controlled at 14.0 V.

Fig. 8. Under-hood view of the idling start/stop taxi.

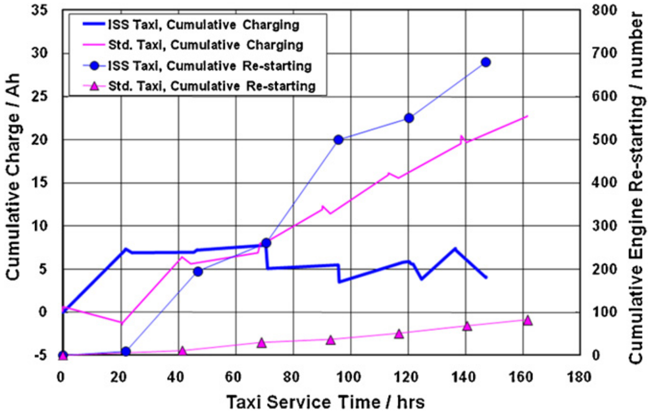

Fig. 9. Comparison of cumulative charge and cumulative number of engine re-starting between the ISS and conventional taxis.

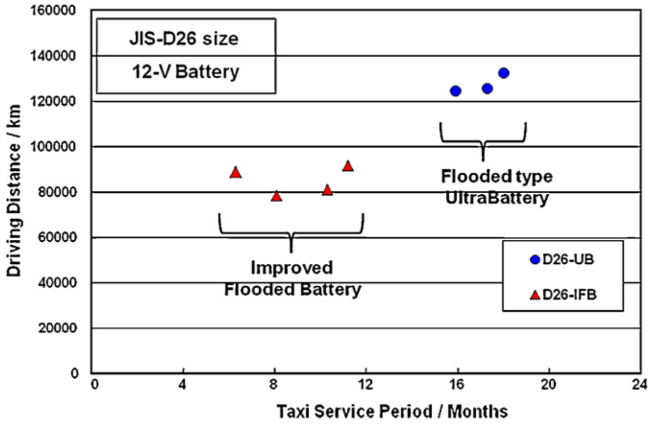

Fig. 10. Field trial performance of the improved batteries and the UltraBatteries in the ISS taxi.

taxi is lower than that of the conventional taxi, namely, 6 Ah cf. 20 Ah. As expected, this indicates clearly that the ISS micro HEV requires more power and energy from the battery than that in the conventional car to meet the frequency of engine re-starting and the energy consumed during vehicle idling. Consequently, even the improved flooded lead-acid batteries could only achieve 80 000–90 000 km before failure (Fig. 10). On the other hand, the UltraBatteries achieved 122 000–132 000 km, which is about 50% longer in service life compared with the improved lead-acid battery.

As with automobiles, hybridization would also be considered as the future trend for energy-storage device because it can marry the best features of the two or more devices in one single unit. In fact, there is another UltraBattery already developed by Mitsubishi Electric Corporation, which combines the Li-ion and the super-capacitor in one single unit cell, http://cranshycars.blogspot.com/2010/02/Mitsubishi-develop-ultrabattery.html.

Finally, I would like to thank The Furukawa Battery and the East Penn Manufacturing for their significant efforts to take the UltraBattery technology to products and also to thank the CSIRO, my wife and family for continuously supporting my research and development works.