

## Electrochemical characterizations of $\text{Na}_2\text{FeP}_2\text{O}_7$ as an aqueous sodium-ion battery electrode

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### ABSTRACT

Recently, research on rechargeable sodium-ion batteries (SIBs) has been rapidly rising to utilize for large energy storage systems (ESSs) beyond lithium-ion batteries (LIBs) due to the fact that sodium is inexpensive and abundant in the earth. While interests on SIBs have grown, concerns over safety using both Na metal as an anode and flammable organic solvents as electrolytes similar to the Li case have also increased. Safety as well as low price is the most important factors especially for large grid-scale ESSs. In that sense, aqueous sodium ion batteries are quite attractive candidates to satisfy with regard to both safety and cost. However, only a few sodium ion insertion materials in aqueous electrolytes have been demonstrated compared to considerable investigations of sodium intercalative materials in nonaqueous electrolytes.<sup>1-5</sup>

Here we introduce a Fe-based sodium intercalative material,  $\text{Na}_2\text{FeP}_2\text{O}_7$ , as a positive electrode for aqueous SIBs.  $\text{Na}_2\text{FeP}_2\text{O}_7$  has already been investigated as a promising cathode for rechargeable SIBs in nonaqueous electrolytes by several groups.<sup>6,7</sup> In this work, we demonstrate reversible sodium ion intercalation properties of this material in aqueous media as well as nonaqueous systems for the first time. Fig. 1 shows the cyclic voltammogram of  $\text{Na}_2\text{FeP}_2\text{O}_7$  at a scan rate of  $1 \text{ mV s}^{-1}$  between  $-1.0$  and  $1.0 \text{ V}$  vs. SCE (Saturated Calomel Electrode) in a  $1 \text{ M Na}_2\text{SO}_4$  aqueous electrolyte using three-electrode cells (Fig. 1). All redox peaks in Fig. 1 match well with those observed in previous results<sup>6,7</sup> of organic electrolytes, and the galvanostatic charge and discharge tests also indicate a reversible de/insertion of sodium ions in aqueous electrolytes. To confirm the feasibility of  $\text{Na}_2\text{FeP}_2\text{O}_7$  as a positive electrode material in aqueous SIBs, we have performed galvanostatic test by narrowing a voltage range from  $-0.1 \text{ V}$  to  $0.9 \text{ V}$  vs. SCE.  $\text{Na}_2\text{FeP}_2\text{O}_7$  delivers approximately  $55 \text{ mAh g}^{-1}$  at 1C-rate in upper voltage regions, corresponding to the insertion of around  $0.57$  mols of Na per mole. At higher rate of 10C, discharge capacity of  $\text{Na}_2\text{FeP}_2\text{O}_7$  is around  $40 \text{ mAh g}^{-1}$ , and  $\sim 97 \%$  of initial capacity is maintained after 200 cycles of 10C charge/discharge (Fig. 2). Detailed electrochemical characterizations including rate performances and cycleability of  $\text{Na}_2\text{FeP}_2\text{O}_7$  in both nonaqueous and aqueous electrolytes will be presented.

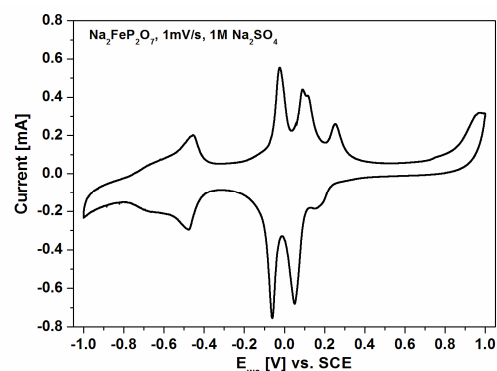


Fig. 1 A cyclic voltammogram of  $\text{Na}_2\text{FeP}_2\text{O}_7$  collected from a three-electrode cell in a  $1 \text{ M Na}_2\text{SO}_4$  electrolyte at a scan rate of  $1 \text{ mV s}^{-1}$  between  $-1.0$  and  $1.0 \text{ V}$  vs. SCE reference electrode.

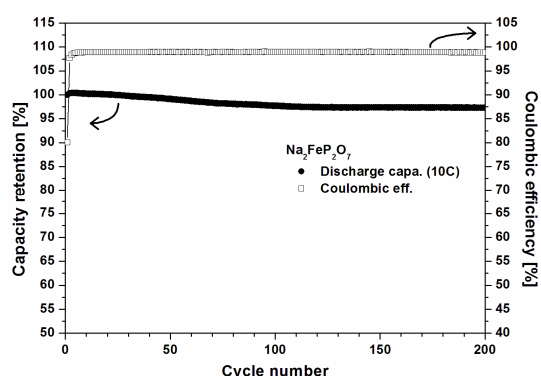


Fig. 2 Discharge capacity vs. cycle number of  $\text{Na}_2\text{FeP}_2\text{O}_7$  at a rate of 10C between  $-0.1$  and  $0.9 \text{ V}$  vs. SCE (1 C-rate =  $97 \text{ mA g}^{-1}$ ).

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