

## **Development of Electrically Conductive ZrO<sub>2</sub>-CaO-Fe<sub>2</sub>O<sub>3</sub>-V<sub>2</sub>O<sub>5</sub> Glass and Glass-Ceramics as a New Cathode Active Material for Na-ion Batteries with High Performance**

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Table 1  $^{57}\text{Fe}$ -Mössbauer parameters of  $x\text{ZrF}_2$  glasses before and after heat treatment at 500 °C for 100 min.

$x$ mol%	before				after			
	$A$ %	$\delta$ $\text{mm s}^{-1}$	$\Delta$ $\text{mm s}^{-1}$	$\Gamma$ $\text{mm s}^{-1}$	$A$ %	$\delta$ $\text{mm s}^{-1}$	$\Delta$ $\text{mm s}^{-1}$	$\Gamma$ $\text{mm s}^{-1}$
0	100	0.40	0.67	0.50	59	0.37	0.33	0.35
					41	0.30	1.09	0.56
10	100	0.40	0.68	0.50	71	0.38	0.28	0.31
					29	0.31	1.27	0.58
20	100	0.38	0.74	0.52	81	0.37	0.28	0.34
					19	0.31	1.55	0.54
30	100	0.39	0.72	0.52	82	0.38	0.28	0.31
					18	0.29	1.24	0.78

$A$ : absorption area ( $\pm 0.5\%$ ),  $\delta$ : isomer shift ( $\pm 0.01 \text{ mm s}^{-1}$ ),  $\Delta$ : quadrupole splitting ( $\pm 0.02 \text{ mm s}^{-1}$ ),  $\Gamma$ : Linewidth ( $\pm 0.02 \text{ mm s}^{-1}$ )

Table 2  $^{57}\text{Fe}$ - Mössbauer spectra of  $x\text{ZCFV}$  glasses before and after heat treatment at 500 °C for 100 min.

$x$ mol%	before				after			
	$A$ %	$\delta$ $\text{mm s}^{-1}$	$\Delta$ $\text{mm s}^{-1}$	$\Gamma$ $\text{mm s}^{-1}$	$A$ %	$\delta$ $\text{mm s}^{-1}$	$\Delta$ $\text{mm s}^{-1}$	$\Gamma$ $\text{mm s}^{-1}$
0	100	0.38	0.76	0.52	36	0.39	0.65	0.35
					33	0.39	0.33	0.35
					31	0.32	1.12	0.35
5	100	0.37	0.77	0.49	53	0.38	0.66	0.33
					18	0.40	0.34	0.33
					29	0.35	1.16	0.33
10	100	0.39	0.75	0.50	37	0.38	0.66	0.32
					34	0.40	0.34	0.32
					28	0.33	1.13	0.32
15	100	0.38	0.74	0.49	100	0.40	0.30	0.37

$A$ : absorption area ( $\pm 0.5\%$ ),  $\delta$ : isomer shift ( $\pm 0.01 \text{ mm s}^{-1}$ ),  $\Delta$ : quadrupole splitting ( $\pm 0.03 \text{ mm s}^{-1}$ ),  $\Gamma$ : Linewidth ( $\pm 0.02 \text{ mm s}^{-1}$ )

Table 3 Comparison of the capacity of Na-ion batteries containing sodium vanadate as a cathode active material.

compounds	current density [mA g <sup>-1</sup> ]	capacity [mAh g <sup>-1</sup> ]	maintenance rate[%] (cycle)	ref.
Na <sub>0.33</sub> V <sub>2</sub> O <sub>5</sub>	0.02	83	65(30)	[49]
NaV <sub>6</sub> O <sub>15</sub>	100	92	74(30)	[50]
Na <sub>2.46</sub> V <sub>6</sub> O <sub>16</sub>	50	62	88(100)	[51]
Na <sub>1.1</sub> V <sub>3</sub> O <sub>7.9</sub>	50	125	66(190)	[52]
Na <sub>1.25</sub> V <sub>3</sub> O <sub>8</sub>	200	158	95(200)	[53]
Na <sub>0.282</sub> V <sub>2</sub> O <sub>5</sub>	300	104	76(1000)	[54]
25Na <sub>2</sub> O•65V <sub>2</sub> O <sub>5</sub> •10P <sub>2</sub> O <sub>5</sub>	5	184	- (5)	[17]
HT25Na <sub>2</sub> O•65V <sub>2</sub> O <sub>5</sub> •10P <sub>2</sub> O <sub>5</sub>	5	173	- (5)	[17]
HT20ZrO <sub>2</sub> •70V <sub>2</sub> O <sub>5</sub> •10Fe <sub>2</sub> O <sub>3</sub>	50	153	45(30)	this study
HT20CaO•70V <sub>2</sub> O <sub>5</sub> •10Fe <sub>2</sub> O <sub>3</sub>	50	138	59(30)	this study

HT: heat-treated