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Supporting information

P-doped in situ induced Se vacancy enhances the supercapacitor performance of $NiCo_2Se_4$

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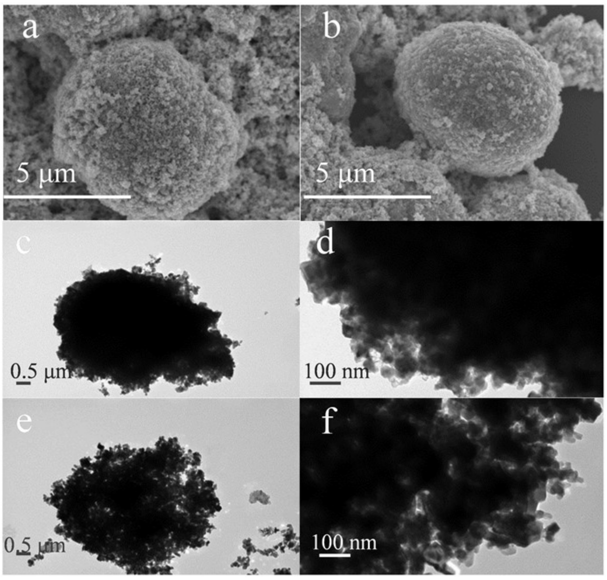

Fig. S1 (a) SEM images of $NiCo_2Se_x$-$P_{0.5}$, (b) SEM images of $NiCo_2Se_x$-P_2, (c-d) TEM images of $NiCo_2Se_x$-$P_{0.5}$, (e-f) TEM images of $NiCo_2Se_x$-P_2.

SEM images of $NiCo_2Se_x$-$P_{0.5}$ and $NiCo_2Se_x$-P_2 are shown in Fig. S1(a-b). After the phosphating treatment, both $NiCo_2Se_x$-$P_{0.5}$ and $NiCo_2Se_x$-P_2 showed a microsphere morphology with an average size of 5 μm, and the spherical surface was covered with a large number of nanoparticles. The low-magnification TEM images of $NiCo_2Se_x$-$P_{0.5}$ and $NiCo_2Se_x$-P_2 are shown in Fig. S1(c-f), and their size is about 5 μm, which is in agreement with the SEM results. Compared with $NiCo_2Se_x$-P_1 material, they are all microspheres, but further observation can be found that the surface of $NiCo_2Se_x$-P_1 material is needle-like, which may be that the amount of phosphorus doping will have some effect on its morphology, resulting in differences in the surface structure of the material. As for $NiCo_2Se_x$-P_1, the mesh structure formed by interconnecting neighboring nano-needles on its surface has abundant pores, and this multi-channel structure can accelerate the rapid penetration of electrolyte ions in the active material. Therefore, the electrochemical performance of $NiCo_2Se_x$-P_1 obtained after phosphorization treatment are better than the other two samples. Based on this we consider $NiCo_2Se_x$-P_1 as a typical sample for research.

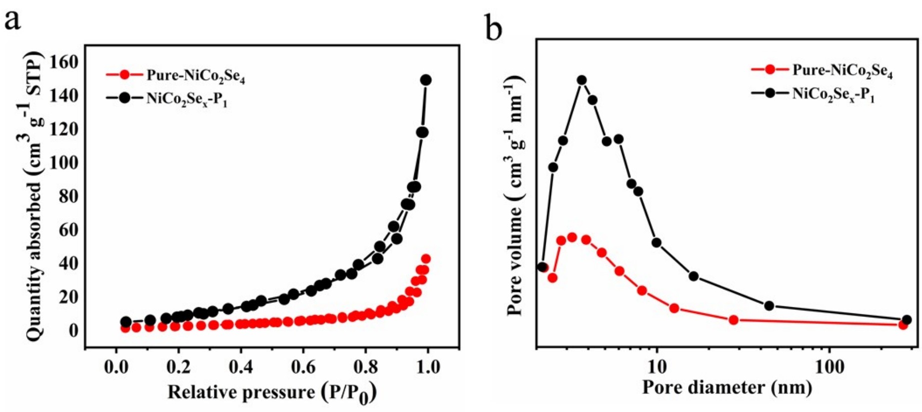

Fig. S2 (a) N_2 adsorption/desorption isotherm, (b) Pore size distribution.

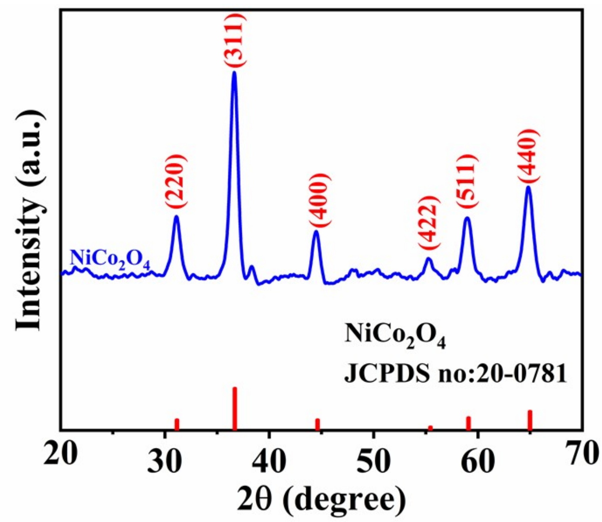

Fig. S3 XRD pattern of NiCo precursor.

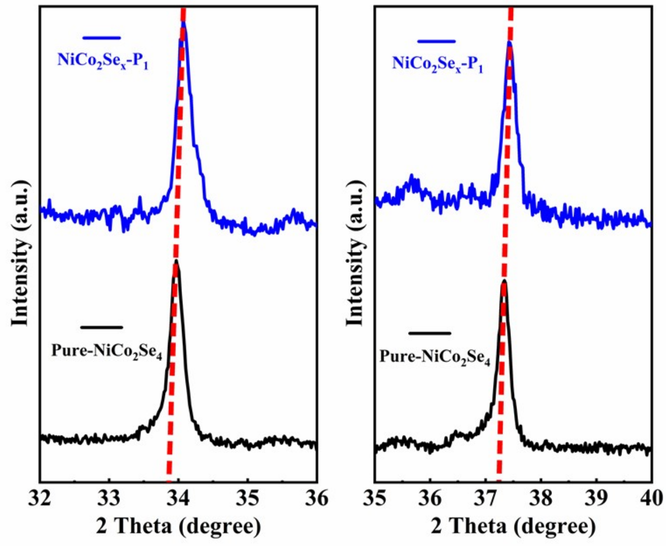

Fig. S4 XRD comparison of (210) and (211) crystal planes of Pure-$NiCo_2Se_4$ and $NiCo_2Se_x$-P_1.

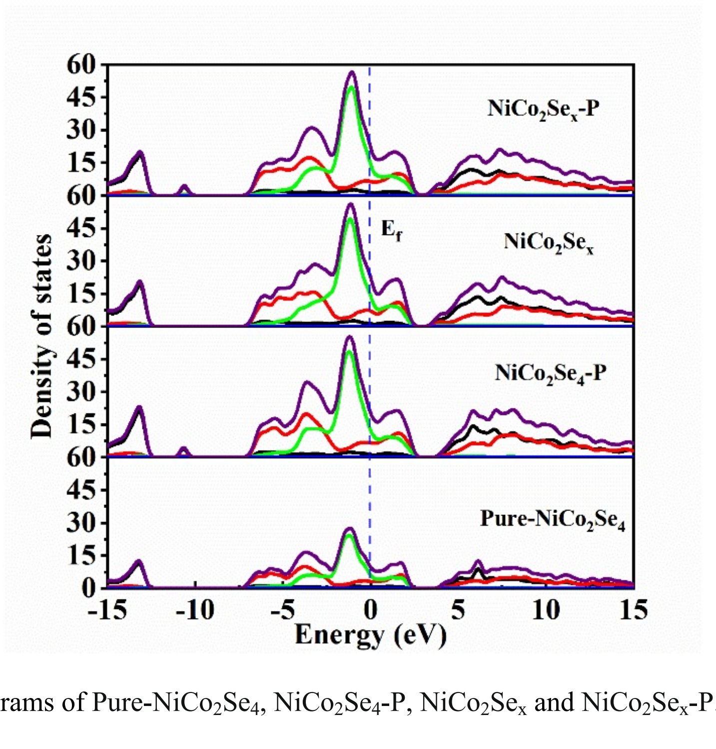

Fig. S5 DOS diagrams of Pure-$NiCo_2Se_4$, $NiCo_2Se_4$-P, $NiCo_2Se_x$ and $NiCo_2Se_x$-P.

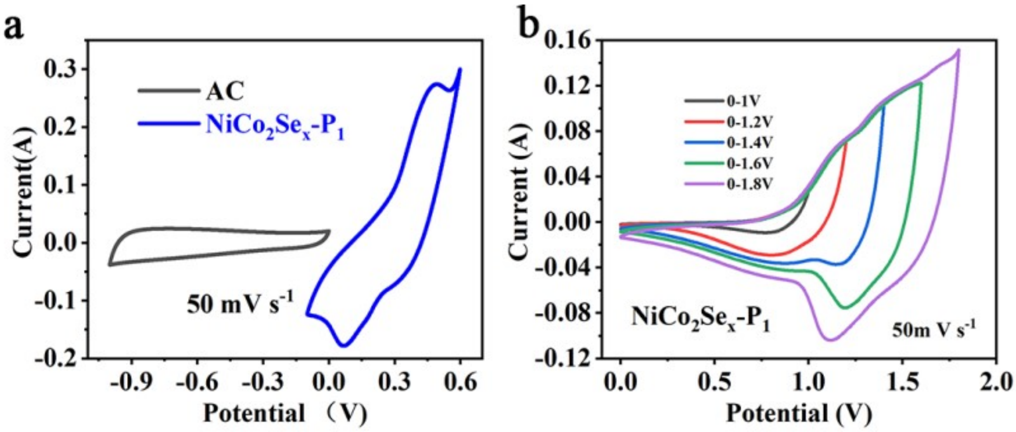

Fig. S6 (a)Comparison of CV curves of AC electrode and $NiCo_2Se_x$-P_1 electrode at 50 mV s^{-1} scan rate, (b) CV curves of different voltage windows at $NiCo_2Se_x$-P_1/ /AC scan rate of 50 mV s^{-1}.

Table. S1 Performance comparison of $NiCo_2Se_x$-P_1//AC devices with recently reported hybrid supercapacitors

Supercapacitor device	energy density (Wh kg^{-1})	power density (W kg^{-1})	Reference
$CoNi_2S_4$//Bi_2O_3	86.6	1600	1
$Ni_2Co_4Se_4$//HPC	34.8	399.9	2
$NiCo_2Se_4$/rGO//TRGO	37.83	1433.55	3
$(Ni_{0.33}Co_{0.67})Se_2$ CHSs//AC	29.1	800	4
$NiCo_2Se_4$//AC	25	490	5
$Ni_{0.67}Co_{0.33}Se$//RGO	36.7	750	6
$(Ni_{0.5}Co_{0.5})_{0.85}Se$//carbon	70.58	320.02	7
$NiCo_2Se_x$-P_1//AC	94.61	799.92	This work

References

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