

Piezoelectrochemical Materials in Commercial Lithium Ion Batteries

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A well-known phenomenon in the lithium ion battery field is the volumetric expansion of the electrodes during the charging and discharging of the battery. Although this phenomenon poses many problems for the design of more efficient and safer batteries, it is possible we can use it to our advantage by driving this mechanism the other direction—in other words, applying a volumetric change to the battery to elicit electrochemical potential. Materials in which mechanical energy is directly converted into electrochemical potential are called piezoelectrochemical (PEC) materials, and the PEC effect has been demonstrated in multiple systems^[1-6], including electrodes in lithium ion batteries^[1,7].

One motivation for studying the mechanism behind the PEC effect is for applications in mechanical energy harvesting. PEC materials can provide a potentially permanent power source for micro-electronics and other applications in which connection to a traditional power source is not practical. In PEC materials, the chemical potential of ions is affected by an applied stress, and under such circumstances these materials can be used in a thermodynamic cycle to harvest energy, at a relatively slow rate commensurate with the kinetic transport in electrochemical systems^[1]. The slow rate allows PEC materials to harvest at low frequency ranges (less than 1-10Hz), which are not captured by traditional mechanical energy harvesting materials. PEC systems also have higher energy density compared to other mechanical energy harvesting systems^[1]. Therefore, PEC materials would be useful in mechanical energy harvesting applications that harvest low frequencies at high energy densities.

Because little is known about the PEC effect, it is useful to study how it behaves in a well-defined system of a known quality, such as commercial lithium ion batteries. Previous work^[1,7,8] has demonstrated that commercial lithium cobalt oxide (LCO) batteries exhibit the PEC effect, as both the lithium cobalt oxide cathode and lithium-intercalated graphite anode are PEC materials. The coupling factor between the change in equilibrium potential and applied mechanical stress was approximated as a function of the state-of-charge (SOC) of the battery by measuring the differential expansion and voltage^[1].

Ongoing work has demonstrated how to use piezoelectrochemical energy harvesting to increase the voltage generated from lithium ion batteries by combining several batteries together. Based on how voltages add in series, one might expect PEC voltages to add in series-connected cells. To demonstrate this experimentally, we characterized the coupling factor of the PEC effect as a function of SOC for commercial 500mAh LCO batteries. The batteries were then charged to the optimal SOC, and placed in the three different configurations depicted in Figure 1a. Active cells were connected in parallel to a resistor to reference cells; the active cells were mechanically cycled from 10 MPa to 0.1MPa at a frequency of 200 μ Hz. The voltage generated by the PEC effect was quantified by measuring the voltage drop across the resistor. The measured voltage of the three configurations is plotted in Figure 1b. As expected, the PEC voltage can be increased by compressing batteries in series. Increasing the PEC voltage generated would allow the effect to be used in practical applications such as micro-energy devices.

Much of how the PEC effect works is still not understood. Future work will attempt to address some of the open questions, including what the link is between coupling factor and

crystal structure. To gain further understanding of this phenomenon, future work will investigate how the PEC effect acts in single crystalline systems, in order to reduce the complexity of the active material structure. The PEC effect will also be studied in systems that can withstand high compression, like solid-state batteries, in order to increase the generated voltage by increasing the applied stress.

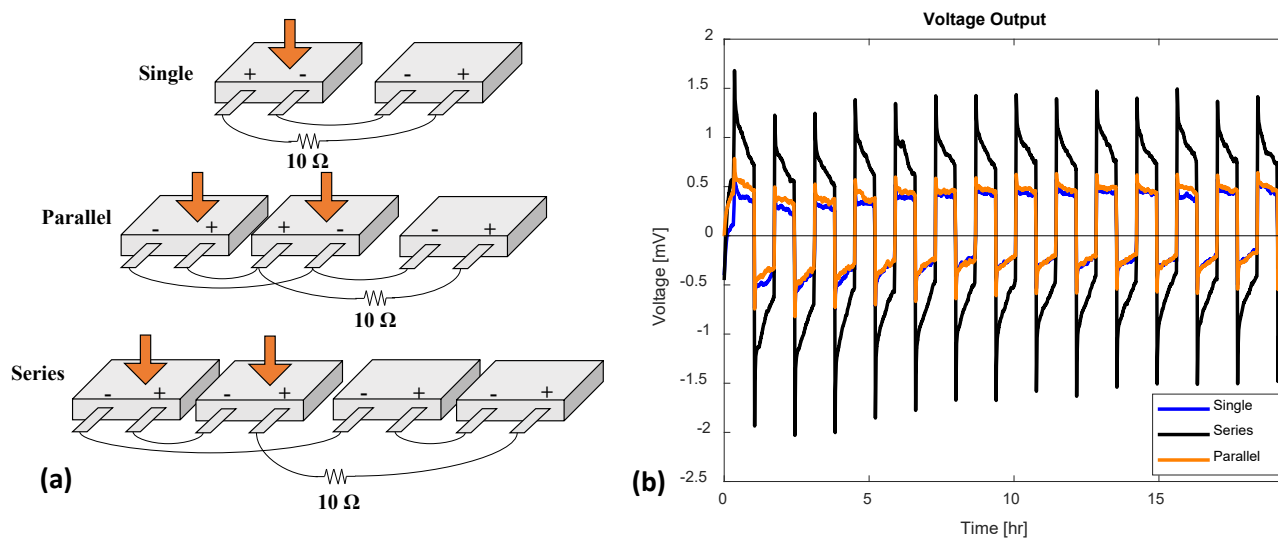


Figure 1: (a) Three wiring configurations of commercial lithium ion pouch cells were tested: single, parallel, and series. The active cells were parallel soldered through a resistor to reference cells, and then the active cells were mechanically cycled as the voltage across the resistor was measured. (b) The measurement of the voltage across the resistor for each of the configurations shown in 1a. As expected, the voltage of the series configuration is higher.

References

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