Unlocking a Tenfold Increase in Battery Performance: Poly(citric Acid) as a Novel Binder for Silicon Anode Batteries

Tae, Ryan (School: Jericho High School)

Silicon (Si) anodes could revolutionize lithium-ion batteries by expanding capacity eleven-fold. However, Si expansion during charging compromises battery integrity, preventing practical application. Polymeric binders can prevent this harmful expansion. Previous computational studies suggested that binders with ultra-high COOH density (33% COOH/monomer) optimized silicon stabilization, despite two opposing mechanisms: binder adhesion and electrolyte consumption. While these computational studies successfully validated high binder adhesion in ultra-high COOH density binders, the role of electrolyte consumption remained unclear. Therefore, this study aimed to clarify the chemical interactions within silicon anodes through wet-lab synthesis and validation of a particularly promising novel binder called poly(citric acid) (PCA) which has the highest known COOH density to date (43%). PCA was polymerized through repeated esterification of citric acid (CA) and characterized by Fourier Transform Infrared spectroscopy, validating successful PCA synthesis. Ion chromatography showed that PCA had 0.1% electrolyte decomposition compared with other binders, whereas NMR spectroscopy of the electrolyte solutions revealed that PCA did not produce toxic PF_5 and POF_3 gases found in other binders. When PCA was incorporated into physical silicon anodes and compared against poly(acrylic acid) and poly(vinylidene fluoride), PCA batteries exceeded their counterparts. PCA had 50% total capacity retention after 40 cycles compared to PAA (13%) and PVDF (1%). This study establishes ultra-high COOH-density binders as a solution for next-generation silicon anodes, demonstrating that PCA offers favorable chemical properties and superior battery performance to meet global sustainable energy demands.

Awards Won:

Second Award of $2,400

Chemistry and the Law: Third Award of $2,000