A Course in the Materials for Battery Technology

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Abstract

With the increase in hybrid and electric vehicles, the advanced energy storage industry is a rapidly growing field. The companies in this industry are looking for engineering graduates with the skills and training to work in the area of energy storage. In order to meet this demand, Grand Valley State University has developed a course in the materials involved in energy storage. The course focuses on the active materials within lithium-ion batteries but other energy storage systems are also discussed. The course covers the anode and cathode active materials, electrolytes, and the interactions between each of these components. It also presents the testing of the materials as well as the selection of the appropriate materials and systems for specific applications.

This paper will present an overview of the content of the Materials for Energy Storage course. This course is currently being offered for the second time and is continuing to be updated and modified. The updates from the initial offering will be discussed.

Introduction

California launched the Low Emission Vehicle (LEV) program over two decades ago, helping stimulate the hybrid market. In 2013, governors from California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island and Vermont, representing a quarter of the United States' car-buying market, started pushing for more zero emissions vehicles (ZEVs), with a target of 3.3 million electric vehicles on the road by 2025 [1]. As the number of electric vehicles being produced increases, the need for batteries for these vehicles must also increase.

West Michigan is home to an emerging advanced energy storage industry. The region has the highest concentration of lithium-ion battery manufacturing and supporting industries in North America, with over $1 billion in investment by fortu PowerCell, Johnson Controls, LG Chem, and Toda America and thousands of new jobs [2]. As production at these energy storage companies increases, there will be an increased demand for employees with the skills and training necessary to work in this industry. To meet this demand, it will be necessary to strengthen the knowledge of the workforce by updating existing curricula to include alternative energy concepts and skills, as well as to design new curricula, certifications, and degrees [3].

Universities are beginning to address this recent need for energy curricula through educational programs in energy storage for both stationary and vehicular applications [4-7]. The School of

Engineering (SoE) at Grand Valley State University (GVSU) has developed a class in Materials for Energy Storage to help prepare students with foundational energy knowledge to work in the growing advanced energy storage industry in west Michigan and nationwide.

This paper will provide an overview of the content of the Materials for Energy Storage course that was developed at GVSU. The updates being incorporated based on feedback from the pilot offering will be discussed.

Organization of the Course

Research has shown that the general class organization strategies of questioning, organizing lessons, providing feedback, starting lessons with a review, and ending with closure are relevant across all grade levels and content areas [8]. The Materials for Energy Storage course has been organized to incorporate these strategies into the structure of the individual class periods. Additionally, the topics for the entire semester are organized so as to integrate review and feedback prior to progressing to new topic areas. Research has also shown that students will tend to take one of three main approaches to their courses. Some students will take a surface approach by relying on memorization, while others will take a deep approach by asking questions and exploring the limits of applicability of new information, and others that will take a strategic approach by taking a surface approach when sufficient and only taking a deep approach when necessary [9]. The assignments and examinations in this course were designed to require a deeper approach to understanding the information presented. Students must research information on their own and then relate that information to what has been presented by the instructor as well as by other students.

This is a three credit-hour course that is 15 weeks long. It is a lecture/discussion course without a laboratory component. This course is cross-listed for both graduate and undergraduate students, with additional requirements for the graduate students. The general arrangement of topics in this course is that it starts with an introduction to the electrochemical reactions that occur in an electrochemical cell, the individual components of the cell are then studied in detail before the electrochemical energy storage system is considered as a whole and the contributions and interactions of the various components are analyzed. When focusing on the various active materials within the electrochemical cells, the benefits and drawbacks of each material are discussed and used to identify active materials for specific battery applications.

Course Content

The textbook that is used for this course is “Advanced Batteries – Materials Science Aspects” by R.A. Huggins [10] (chapters 1-4, 7, 9, 14-16) and “Lithium Batteries: Science and Technology” by G.-A. Nazri and G. Pistoia (Eds.) [11] is used as a supplemental reference. A schedule of the topics for the course can be seen in Table 1. After a brief electrical, materials, and chemistry refresher, an introduction to batteries and battery terminology is presented. The concepts of primary (single use) and secondary (rechargeable) batteries are introduced along with the components of electrochemical cells and the various cell configurations. There is then a brief overview of the common battery chemistries, such as nickel cadmium, nickel-metal hydride, lead acid, reusable alkaline, and lithium ion, with the properties, materials, and chemical reactions that occur in the cells being discussed. The lithium ion battery (LIB) is studied in the greatest depth within this course, therefore, the manufacturing processes involved in making a LIB is presented and a tour of a LIB manufacturing facility is organized for the class.

Table 1. Schedule of topics for the Materials for Energy Storage course.

Week	Topics
1	Introduction to the course and review of the syllabus Electrical, chemistry, and materials refresher
2	Introduction to batteries
3	Battery manufacturing processes Electrochemical reactions
4	Reaction mechanisms and important practical parameters Binary and ternary phase diagrams for electrode materials
5	Cathode materials
6	Cathode materials continued
7	Anode materials
8	Electrolyte materials and solid electrolyte interphase (SEI)
9	Break week - no class
10	Electrochemical testing and typical response of common materials Material characterization techniques
11	Life testing and capacity fade mechanisms
12	Recent advances in battery technology Other advanced energy storage methods
13	Tour of Johnson Controls battery manufacturing facility
14	Applications of battery technologies
15	Final project presentations Course evaluations
16	Final Exam

Before discussing the active materials within the electrochemical cells, first the general chemical and electrochemical reactions, the driving forces for the reactions, the reaction mechanisms, and important practical parameters for electrochemical systems are presented. With this background, the active materials for cathodes are then discussed and the impact of the material structures on the performance of the cells is examined. The common material structures such as layered, spinel, and olivine structures are reviewed and then specific LIB cathode active materials that have these structures are introduced. The materials examined are $LiCoO_2$, $LiMn_2O_4$, and $LiFePO_4$ as these are some of the most commonly used cathode materials in LIBs. The students are also required to select a cathode material for which they complete a literature review and present their findings about uses, performance, and research being done with additives or variations that allow for optimization of the properties.

The next topic is the active materials for anodes. The use of lithium as an anode is first presented along with its limitations. The very prevalent use of carbonaceous anode materials is then discussed with a great focus placed on the graphite structure. The importance of the layered graphite structure for the intercalation of lithium into the anode is explained. As with the cathode materials, the students are also required to select an anode material for which they complete a literature review and present their findings about uses, performance, and research being done to optimize the properties.

After the cathode and anode materials have been presented, electrolytes are then considered. Both liquid and solid electrolytes are discussed. The importance of non-aqueous organic solvent electrolytes containing lithium salts as liquid electrolytes is reviewed. The commonly used organic solvents are introduced along with the benefits and limitations of each and how they can be mixed to obtain the most desirable properties. The use of ionic liquids as electrolytes is also reviewed. Solid electrolytes and the material structures and types of disorders that help to promote the ionic conduction through solid electrolytes are presented.

The interaction between the various materials is discussed, with a particular focus on the interaction between organic solvent electrolytes, lithium, and the anode materials, resulting in the solid electrolyte interphase (SEI) layer formation. The capacity fade due to the SEI layer that develops during the formation process when the cells are initially cycled is presented. Other factors that affect capacity fade after the formation process are considered and the students complete a literature review to identify methods being studied to address capacity fade in LIBs.

Methods of characterizing the materials such as electron microscopy, electron diffraction, and x-ray diffraction are presented, along with methods of testing the cell performance. Along with the discussion of the cell testing, the responses of the materials and the factors that affect their performance are considered. Finally, the applications for battery technologies are discussed as well as the requirements for the various applications and selection of appropriate battery chemistries.

Course Updates

The organization and content of the course described above is the result of updates made after the pilot offering of the course. A survey was administered at the end of the pilot offering and the student responses were used to refine the course. In addition to organizational and content updates, student responses indicated that they wanted clearer learning expectations. To address this, review sheets and study guides have been developed to provide clarification of expectations prior to quizzes or examinations.

During the pilot offering, students prepared presentations on various materials used in the electrochemical cells, however, they found that they were not very confident in their ability to compare materials and evaluate tradeoffs in performance between materials. Therefore, when the students select the materials that they will be studying, they also determine as a class which properties or performance parameters will be identified for each material so that they can all be compared and contrasted using the same properties and parameters. Once the students have presented their findings, a compilation of the properties and parameters is prepared and distributed to summarize the various materials.

The student responses indicated a lower confidence in their ability to describe testing methods and typical responses of common materials. A method used to address this and to obtain a greater depth of coverage has been to provide journal articles that describe the testing of various battery materials which can be reviewed by the students in preparation for the class and then discussed in small groups during the class. Small group discussions and problem solving are encouraged. This is one area that was identified as being beneficial during the pilot offering and has been continued and added to during the second offering of the course.

The students receiving graduate credit for the course are required to complete an additional assignment to investigate contributions to capacity fade and methods to reduce capacity fade during the initial formation procedure as well as over the life of the battery. Rather than presenting the information to the class as a whole, the graduate students are arranged into small groups with the undergraduate students and they present the information that they gathered from a thorough review of technical publications. This is intended to build the confidence of the graduate students and provides exposure of the topics to the undergraduate students in addition to the exposure that they obtain from the lecture on the topic.

Conclusions

The Materials for Energy Storage course has been designed to provide GVSU students with knowledge to participate in the advanced energy storage industry. It is organized to present the materials for the individual cell components and then looks at the interactions between the various components. The benefits and drawbacks for various cell chemistries are identified and used to select appropriate batteries for specific applications.

Using feedback from the students in the pilot offering, the course has been updated for its second offering. The learning expectations have been more clearly identified for the students through the use of review sheets and study guides for quizzes and examinations. Group activities and discussions are continuing to be utilized to increase the students' active participation in the class. This course will continue to be refined based on further assessments of the second offering.

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