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# The practice of problem-based investigative-teaching reform in semiconductor physics course

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## ABSTRACT

Semiconductor physics is an important basic course for the students of the majors of applied physics, optoelectronics, and microelectronics. The authors have been carrying out investigative-teaching reform in semiconductor physics teaching. Firstly, the teaching content was re-structured based on scientific problems. Secondly, the students were placed in groups to discuss different scientific problems and to present a few short science-reports. Thirdly, micro-lesson videos were produced for the students to study and analyze before or after class. With comparative analysis, we find out that the semiconductor-physics curriculum content was greatly enriched. In addition, the students' learning motivation and scientific thinking ability increased, and their innovation ability was improved. Overall, the teaching quality of the semiconductor physics course could be significantly improved.

**Keywords:** investigative-teaching reform, problem-based, semiconductor physics.

## 1. INTRODUCTION

As a branch of solid physics, semiconductor physics focuses on the atomic state, the electronic state and the basic laws of charge-carrier movement based on the crystal structure and band theory<sup>1</sup>. Semiconductor physics is an important fundamental course for students of the majors of applied physics, optoelectronics, and microelectronics. Its teaching quality affects subsequent courses such as semiconductor device physics, the integration process, as well as the students' future employment and professional development<sup>2,3</sup>.

However, current semiconductor physics teaching is facing some severe challenges in the following areas. Firstly, the available time for teaching has been cut down. At present, both society and industry introduce several new requirements for the students of engineering, which emphasize practical skills, knowledge application ability, and the ability to combine theory with practice<sup>4</sup>. The teaching curriculums for engineering majors are constantly adjusted. As a result, the theoretical class hours are reduced and practice time increases. The semiconductor-physics class-time also has been compressed, and the class hour is only 40 - 48 for applied-physics and optoelectronics majors in the author's institution. Secondly, semiconductor physics is both intensive and interdisciplinary, which creates challenges for the students<sup>5</sup>. This course covers a lot of material, as well as other course, such as solid-state physics, quantum mechanics, and mathematical methods, which requires strong mathematical foundation. In particular, students with a weak background in solid-state physics, tend to find it is difficult to study semiconductor physics. During their study, they generally feel that formulas are complicated and they have problems understanding concepts and key points. In addition, with the rapid progress in semiconductor science and technology, new theories and problems emerge continually, which makes their study more difficult. Furthermore, the traditional teaching mode, where teachers are at the center and classroom lectures are the main teaching mode, is not suitable to engage students. And furthermore, it is not in favoring of enhancing the students' self-learning ability. The traditional teaching mode emphasizes output of teachers, who focus on the derivation of a formula and devote oneself to transfer knowledge. Correspondingly, students tend to learn passively and little about application of knowledge. This often leads to an "I can't see the forest for the trees" situation, and the students gradually lose learning interest. Even if the students have solid textbook knowledge, their independent learning ability remains underdeveloped.

It can be concluded that the traditional teaching mode is unsuitable to teach semiconductor physics

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effectively. In order to deepen the students' understanding, knowledge, and concepts, as well as broaden their horizons, problem-oriented research teaching reforms were implemented with respect to teaching semiconductor physics.

## 2. THE CONCRETE MEASURES TO IMPLEMENT PROBLEM-ORIENTED TEACHING

### 2.1 Optimization and integration of teaching material based on scientific problems

Due to the complexity of many theoretical subjects, such as quantum mechanics, statistical physics, mathematical methods, and lack of background knowledge in solid-state physics, some students in the author's school find it difficult to learn semiconductor physics. In view of this situation, the author optimized the teaching content based on scientific issues. Firstly, the important pieces of knowledge were arranged systematically throughout the course. Both the historical development of a theory and potential problems were introduced in the form of a problem. This approach provides an opportunity for the students to analyze, research, and discuss. Then, the teacher conducted a systematic review of the whole process. For example, before semiconductor energy-band theory was explained, several problems were pointed out: the characteristics and solved scientific problems of the free electron model, shortcomings of the free electron model, a comparison between Bloch's and free electrons, the general characteristics of Bloch electrons, etc. This was followed with an explanation of energy-band theory with which other scientific problems could be solved.

Students were put in groups to tackle these problems. After class, for one of the questions, each group accessed data and related literature, which were used to analyze and discuss the problems. In the next lesson, a group leader would report the results of each question in a report about 10 - 15 minutes. Both the teacher and students of the other group followed up with a question and answer session. After the discussion, the teacher revised errors and offered a systematic explanation of the question and answer. In addition, some complex theoretical formulas were deduced in brief, and the underlying physics was explained in detail. In the end, the teacher refined the theoretical knowledge, so that students could acquire knowledge more systematically and avoid fragmentation of knowledge. The whole process, from selecting problems and researching materials to analyze and discuss problems, served to stimulate the students' learning motivation<sup>6</sup>. In addition, this method helped facilitate independent learning and cooperation. It also helped the students to learn the theoretical material more systematically, which enabled the students to develop their scientific and critical thinking.

Secondly, we added some history of physics and currently popular topics to specific chapters. For example, when we discussed the characteristics of semiconductors, both the discovery process of semiconductor features and the related theories were introduced. Also, the history of the microelectronics industry and energy-band engineering were introduced, together with research hot-spots and the future direction of the semiconductor industry. Furthermore, Nobel-prize winners and other outstanding physicists were introduced. For example, the success and failure of William Shockley and Jack Kilby as well as Gordon Moore's achievements, Ruersi - Alferov's contribution were mentioned, which helped to stimulate the students' learning interest. It also improved the students' ability to break with conventional thinking patterns<sup>7</sup>.

### 2.2 The integration and recording of micro lessons about some difficult topics

Because the subject of this course is more complex and the class time was limited, some problems were difficult to understand during class time. For some topics, we produced several short videos (micro-lessons) for students to preview before each class and/or review after class. We did this for certain important topics like reciprocal space, density calculation,

$$f(\varepsilon) = 1 / \{1 + \exp[(\varepsilon - \varepsilon_f) / kT]\} \quad (1)$$

and  $\varepsilon_f$ , energy-levels of impurities, non-equilibrium carrier generation, carrier generation and recombination, the space-charge region of a P/N junction. These were recorded in micro-lesson videos (7-10 minutes long) which were optimized to attract student's attention using a problem<sup>8</sup>. For example, the video about reciprocal space began with the question: What is the relationship between a Bravais-lattice vector

$$(\vec{R}_L = l_1\vec{a}_1 + l_2\vec{a}_2 + l_3\vec{a}_3) \quad (2)$$

and a reciprocal-lattice vector

$$(\vec{k}_h = h_1\vec{b}_1 + h_2\vec{b}_2 + h_3\vec{b}_3) \quad (3)$$

The video mentioned the formation of a space charge region at the P/N junction, addressed the problem of how solar cells work as a starting point, and explained the general physical principles of solar cells. It also addressed the development of the photovoltaic industry and its current situation. The micro-video, "Carrier recombination radiation", emphasized "How does a light-emitting diode (LED) produce light, and what determines its color?" The video then highlighted carrier-generation and recombination theory, which was used to explain, in simple terms, the working principle of a light-emitting diode (LED), as well as the development of LED lighting. At the same time, the invention of the blue energy-efficient LED, which won the 2014 Nobel Prize in physics, was mentioned, and existing problems between red LED and blue LED were compared. These micro-videos were convenient to view before and after class, and they strengthened the students' understanding of key knowledge<sup>9, 10</sup>. They also improved the ability to combine theory and practice.

### **2.3 Small "flipped classroom" - reports during class-breaks**

To produce comprehensive research our school established 2011 college in 2013, which implements small-class teaching and practices a variety of teaching methods. Optoelectronics is one of the majors of 2011 college. To meet the strategic objectives of our school, we use break time to do "flipped classroom" reports. After finishing band theory, the students were asked to find information and prepare a 10 - 20 minute PowerPoint presentation about the topic of wide bandgap materials, considering their own interests and project work or other relevant course content. A semester later, the students had prepared a total of about 30 reports. The reports were rich and colorful, covering a wide range, from research of students' participation or device development, to the semiconductor- industry development outlook. The reports were shared with other students during break-time. Most of them were carefully prepared and well presented. Some even used humorous language, and received applause. These short reports greatly enriched the teaching content and broadened horizons. They also provided inspiration to teachers. The teacher produced a summary and comments of all presentations, according to the use of language and the quality of the answers to the questions. To our surprise, the students were very fond of this kind of "class-break". To produce the reports, the students used the library and other sources to collect information, which greatly stimulated interest in research. It also improved the interaction between teachers and students<sup>11, 12</sup>.

## **3. EVALUATION AND COUNTERMEASURES OF REFORM EFFECT**

The reform of problem-based investigative-teaching in two classes of students has achieved several positive results. Firstly, the motivation to study was improved, and the classroom atmosphere became more active. Secondly, the students' ability to study and research independently was enhanced. They often discussed various problems with teachers and other students. Thirdly, compared with regular students, both test-results and pass-rates have improved significantly. Fourthly, as a foundation course, semiconductor physics has become well established, the course content has become more extensive, and the students have acquired knowledge more reliably, which lays a solid foundation for other courses. Of course, there are also some drawbacks and problems in practice. For example, due to poor skills in independent learning and lack of knowledge, a few students seldom participated in the reformed curriculum and the effect of the reform was not obvious for them. Moreover, most of the current semiconductor physics textbooks are relatively very complex, which makes them less suitable for the new teaching methods. In addition, the conflict between more content and less course time has not been resolved completely.

In order to overcome these problems, the author intends to implement the following improvements: (1) adopting various teaching methods and adjusting them to different levels of students, (2) removing many non-essential theoretical parts while retaining the essentials and complementing the new course. For engineering students, the author could compile semiconductor physics teaching material, which highlights the important concepts and reduce complex mathematical derivation, (3) the author could develop a three-dimensional teaching mode to optimize the students' learning time before and after class by network.

## **4. CONCLUSION**

The investigative-teaching reform enriches the course content, increases motivation, and enhances the students' scientific thinking. The changes demonstrate an improvement of teaching semiconductor physics.

The ultimate goal of all of the teaching reform is to improve the students' understanding and application of knowledge, as well as the ability to find innovative solutions. In future, we should develop more interactive learning activities and make more use of a wide range of information resources.

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