Study on the Free Electron Laser and Condensed Matter Physics based on Computer

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Abstract. With the rapid development of computer technology, laser has been widely used in various fields of scientific research. However, with the development of computer technology, the shortcomings of traditional lasers are more and more obvious. Generally, lasers only work in different wavebands, which can not adjust the laser energy. Therefore, the peak power and average power of the laser are not high. The output power of different wavebands varies greatly, which increases the complexity of the experiment. Therefore, the low power and non adjustable frequency limit the depth and breadth of application. In the dynamics study of condensed matter physics, the energy of many elementary excitations in condensed matter, such as acoustic phonon, magneton, polaron and so on, is in the far-infrared region. In recent years, a new type of laser source, free electron laser (FEL), with adjustable frequency and high power, has been developed in the world, which opens up a new way for the study of condensed matter physics. Firstly, this paper analyzes the related concepts. Then, the classification of FEL is analyzed. Finally, the application of FEL in condensed matter physics is proposed.

Keywords: Free Electron Laser, Condensed Matter Physics, Computer

1. Introduction
Free electron laser (FEL) is a new type of laser device, which is produced by relativistic electrons excited by periodic magnetic field of undulator, stimulated emission and amplification to produce coherent light source[1]. After years of development, free electron laser has become an important scientific field, which is different from the traditional ordinary laser which uses the inversion of the number of particles between specific energy levels of atoms or molecules to produce stimulated radiation[2]. Free electron laser (FEL) uses relativistic electrons in vacuum as the medium, which moves under the constraints of undulator and other external magnetic fields, but is not bound by them. Therefore, FEL is in the quasi free state, which is the reason why FEL got its name. Condensed matter physics takes solid physics as the basis and continues to expand outward, which promotes the achievements of condensed matter physics, which has become a modern new technology, new devices and new materials. In the development of the modern world, we are constantly improving the field of high-tech[3].
2. Related concepts and principles

2.1. Concept of free electron laser
Free electron laser (FEL) is a kind of tunable, high power, coherent radiation source. By accelerating electrons through an electron accelerator, we can get a high-energy electron beam out of an electron accelerator. Then, in a periodically changing magnetic field, we can convert the energy of electron beam to light wave, which will produce electromagnetic wave of spontaneous emission. After resonant cavity, we can output high-power laser with certain frequency. By changing the energy of the electron beam or the oscillator parameters, we can change the frequency of the output laser. Because the input electron beam is pulsed, the output laser has a time structure. Free electron laser (FEL) has the advantages that traditional lasers do not have, that is, wavelength tunability and high power, which broaden the application field of laser.

2.2. Concept of condensed matter physics
Condensed matter physics is a kind of physics based on microcosmic point of view, which is composed of a large number of particles, including molecules, electrons, ions, atoms, etc. Therefore, the relationship between macroscopic physical properties and dynamics is a unique subject. Condensed matter physics itself is based on solid physics and extends outwards. Condensed matter physics includes quasicrystals, amorphous crystals, liquid crystals, dense gases, liquid crystals, liquid metals, glass, electrolytes, gels, liquid helium, molten salts and so on. After continuous development, we have formed a more extensive theoretical system of solid-state physics. With the continuous improvement of condensed matter physics, the research object is also increasing and complex. Condensed matter physics is the largest branch of physics, which has become the most important, rich and active subject in physics. At the same time, condensed matter physics is one of the most important research fields carried out by SSR users.

3. Classification of free electron lasers

3.1. Amplifier-FEL
Amplifier FEL is the most primitive type of FEL. When the external incident seed laser enters the undulator together with the electron beam, the optical field gain will be obtained. At present, amplifier FEL has been very rare.

3.2. Self-amplified spontaneous emission
The self-amplified spontaneous emission does not use seed laser. It is a seed laser which directly takes the spontaneous emission of electrons in the front of the undulator as the back section through a long undulator. SASE has simple structure and continuous adjustable wavelength, which is easier to realize. Therefore, self amplified spontaneous emission becomes one of the mainstream development directions of HF FEL. At present, the shortest wavelength can reach the hard X-ray region, which has a wide application prospect. Because the amplification process of SASE originates from short "noise" radiation, the intensity and fluctuation of spectrum are large. The stability of the beam depends on the stability of the beam.

3.3. Oscillator, OSC-FEL
Osc-fel device is composed of undulator or optical klystron and optical resonator, which does not need seed laser. By using the optical resonator mirror, we can use the reflected light from the spontaneous emission of electrons in the undulator as the seed laser, which has the advantage of tunable SASE wavelength. At the same time, the mirror does not need a long undulator, which can be implemented on the storage ring. The disadvantage of osc-fel is that the mirror of optical resonator is easy to be damaged, especially in the case of short wavelength, which limits the development of oscillator type free electron laser.
3.4. Coherent harmonic generation, CHG-FEL

Both CHG-FEL and HGHG-FEL use optical klystron instead of traditional undulator. Optical klystron is a segmented undulator, which can be divided into three parts: modulation, dispersion and radiation. The modulation section and dispersion section are the same as those of the conventional undulator, which has the dispersion section with strong single period magnetic field. In the modulation section, the seed laser and the incident electron beam can be energy modulated. After entering the dispersion section with strong magnetic field, we can convert the energy modulation into density modulation rapidly because of the long path and large amplitude of the wiggle. Finally, the bunching electrons enter the radiation section to produce coherent radiation, which shortens the requirement of the undulator length.

4. Possible applications of free electron laser in condensed matter physics

4.1. Level dynamics

The dynamic process of electron excitation has always been an important subject. In the optical region, energy level dynamics is a method of time-resolved fluorescence spectroscopy. In the far-infrared region, the fluorescence spectrum of the gas-phase substance can effectively label the molecules. In condensed matter, the process of deexcitation after electron excitation is mainly through the emission of phonons, and the deexcitation of radiation photons is of secondary importance. Therefore, the method of directly measuring fluorescence spectrum is limited. For a single system, we can use the saturation method to measure. Through the frequency modulation and high power of FEL, we can saturate the excited electrons. By pumping, we can make the electron transition to a higher level, which will be a better measurement of laser fluorescence. By this method, we can avoid the measurement of weak far-infrared fluorescence, which makes spectroscopy technology can be used to study the far-infrared energy level dynamics. The measurement process is shown in Figure 1.

![Figure 1. Measurement process of energy level dynamics.](image)

4.2. Dynamics of magnetic materials

Most of the magnetic materials have electron spin excitation energies of $10^5 - 100 \mu m$. The study of magnetic materials is limited to the center of Brillouin zone, that is, the uniform and static magnetic mode. On the excitation magneton, we can use the molecular laser band edge pumping technology, which can excite the magneton. Each photon absorbed produces an exciton magneton pair. When a phonon is emitted, the exciton decays into a low-energy trap, which increases the complexity of the
problem. Through the double magneton absorption process, we can use far-infrared light excitation. Because far-infrared photons cannot be coupled with a single acoustic phonon, only magnetons are produced in the excitation process. Free electron laser has high power pulse and adjustable wavelength, which can excite magnetons in the whole Brillouin region. Figure 2 shows the time-of-flight spectra of magnetons in $\text{MnF}_2$ made by far-infrared laser. Different far-infrared excitation frequencies are used in the upper and lower curves.

4.3. Semiconductor material
The 1980s was a time of great development of semiconductor and electronic industry. Based on the traditional light source and synchrotron radiation, the existing spectrum technology enables us to know a lot about the electronic energy levels of electrons and holes. However, little is known about the transient process of electron to hole excitation, and many phenomena depend on the transient characteristics of excited electrons. The characteristics of FEL enable us to choose the excitation energy and study the time course of the interaction among electrons, phonons and defects.

![Figure 2. The time-of-flight spectra of magnetons in $\text{MnF}_2$.](image)

4.4. Separation delay device SDL
The hard X-ray radiation pulse of the European free electron laser, which will be divided into two parts by the beam splitter, half of this pulse will be reflected to the upper half branch, and the remaining half of the radiation pulse will be reflected to the lower branch. The upper half branch of the delay separation device will select monochromatic X-ray in the bandwidth range for reflection. The reflection wavelength of monochromatic light is determined by Bragg emission angle of Si crystal. We can adjust the angle between incident light and Si crystal plane according to the photon energy demand. Under the delay separation device, the branch will need to select another monochromatic reflection wavelength, which can make the delay between two color pulses reach OPS or negative delay. Therefore, both the upper and lower branches need to be adjustable. The upper branch is responsible for the main delay, which is a rough tuning measure. The lower branch is responsible for additional adjustment, which is a fine-tuning measure. The structure diagram of the separation delay device is shown in Figure 3.
5. Conclusion
The physical significance of FEL has shown that FEL is a very effective spectroscopic tool for studying various interactions, such as electron electron, electron phonon, electron magneton, electron exciton, etc. This provides a new way to establish high resolution spectroscopy. With high power, we can generate enough elementary excitations in condensed states. In addition, we can develop the field of nonlinear optics research, which can be used as a tool for time-resolved research. With the rapid development of computer technology, we can discover and display the application of free electron laser in more detail, which is based on the development of condensed matter physical form.

Acknowledgments
1. Basic research project of basic scientific research business expenses in Heilongjiang Province, project number 2018-KYYWF-0954;
2. Basic research project of basic scientific research business expenses in Heilongjiang Province, project number 2019-KYYWF-1398.

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