Quantum Resonator in A Time-resolved Electron Microscope

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Advancements in electron optical devices, such as aberration correctors and data collection technologies, have enabled transmission electron microscopes to provide images with single-atom sensitivity at sub-angstrom spatial resolution. Observations at the atomic level necessitate intense electron irradiation, which often results in changes to the nanostructure of materials. This makes radiation damage a significant bottleneck issue. The primary method currently is to use cryo-electron microscopy to reduce electron radiation damage in a low-temperature environment. However, the rapid freezing process can potentially alter the sample's morphology, and dynamic information about the reaction process becomes unobservable post-freezing. It has been established that the use of pulsed electron sources can minimize radiation damage to materials. However, even a very low electron dose rate can cause radiation damage to soft materials and those sensitive to the beam. The Quantum Zeno effect has been employed to achieve interaction-free measurement, thereby avoiding the interaction between detection particles and materials. This concept has been experimentally confirmed in optics.

The development of a quantum electron microscope, capable of achieving interaction-free measurements between detection electrons and materials, can help overcome the bottleneck of radiation damage. With the support of the Futian District of Shenzhen, the City University of Hong Kong Futian Research Institute has developed key components of a compact electron microscope equipped with a pulsed electron source. Based on this, the team is working on a quantum resonator for use with a pulsed electron source as a key component to achieve a quantum electron microscope. To enhance the quantum effect of interaction-free measurement, it is necessary to increase the number of electron cycles in the resonator. Unlike optical systems, current electron optical components often experience significant losses when the electron beam is split and re-coupled. We have designed an electron resonator based on a multipole field arrangement that can precisely split pulsed electron beams according to the number of cycles required by the resonator. The use of a pulsed electron source can not only reduce radiation damage and provide time resolution but also effectively control the cycle time of the electron beam in the quantum resonator.

To effectively enhance quantum efficiency and reduce the volume of the resonator, we have also designed other key components to match the quantum resonator, including afocal lenses for deceleration and acceleration, a Kepler multipole lens for correcting the electron beam, prism arrays for circulating the electron beam, and a fast kicker for controlling the pulsed electron beam entering and leaving the resonator. The goal is to effectively enhance quantum efficiency and experimentally verify interaction-free measurement based on the Quantum Zeno effect.

Many vital energy and optoelectronic materials are based on soft materials, and many properties of materials, especially the dynamic responses of nanomaterials under external field stimulation, still contain many unknown elements. The development of a quantum electron microscope based on a pulsed electron source is expected to address the key issue of radiation damage and become a new generation tool for studying soft materials at the atomic scale.