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Technology Offer

Electron beam apparatus and method for generating a pulsed electron beam and application thereof

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Abstract

The present invention relates to an electron beam apparatus and a method for generating a pulsed electron beam, comprising a sequence of electron pulses. This technology involves creating a sequence of emitter excitation pulses, typically laser pulses, to induce radiation-emission of source electron pulses. The pulses are spatially separated into sub-pulses with integer electron numbers (*n*=1,2,3..), and a number state selector device selects specific electron number states to form the pulsed electron beam. This innovation promises applications in electron microscopy, material processing through electron lithography, and potential quantum computing applications.

Advantages

- Reduces noise in electron microscopy and improves imaging quality.
- Enables control of electron pulse statistics and sub-Poissonian electron beams.
- Enhances capabilities of ultrafast electron microscopes.
- Facilitates advancements in electron lithography with better precision.
- Provides applications in quantum computing and free-electron quantum optics.

Potential applications

- High-resolution electron microscopy with reduced noise.
- Ultrafast electron microscopes with enhanced beam control.
- Advances material processing using electron lithography.
- Quantum computing implementations requiring precise electron control.
- Novel free-electron quantum optics experiments and applications.

Background

Traditional electron beam technologies face limitation in pulse generation, such as noise and imaging quality issues. Recent advancements in quantum optics and electron microscopy have highlighted the need for precise control over electron pulse characteristics. Conventional methods struggle with stochastic effects and limited pulse control, affecting applications in microscopy and lithography. The invention addresses these challenges by leveraging Coulomb-correlated electron states and advanced filtering technique to generate pulsed electron beam with tailored statistics, reducing noise and enhancing imaging quality.

Technology

The patented technology features an electron beam apparatus that generates pulsed electron beams through a series of controlled steps. As depicted in Figure 1a.) and b.) the process starts with a laser generating excitation pulses, which then create emitter excitation pulses that induce photoemission from an electron source. These source electron pulses are then spatially separated into sub-pulses by a number state dispersion device. The sub-pulses include integer electron numbers (*n*= 1, 2, 3, ..), with the state selector device choosing specific electron number states for the final beam. The graphical representation in c.) shows the correlation between laser power and the number of states per pulse, illustrating the ability to control pulse statistics. Additionally, the antibunching effect is shown in d.), highlighting the technology's capability to reduce noise. The spectral distribution of different electron states is demonstrated in e-h.), providing insight into the distinct energy characteristics of single, double, triple, and quadruple electron states. This setup includes components like beam-limiting apertures, energy-dispersive devices, and spatial modulators to manage pulse characteristics precisely. The technology enables the generation of low-charge electron pulses and the creation of multi-electron states with distinct properties.

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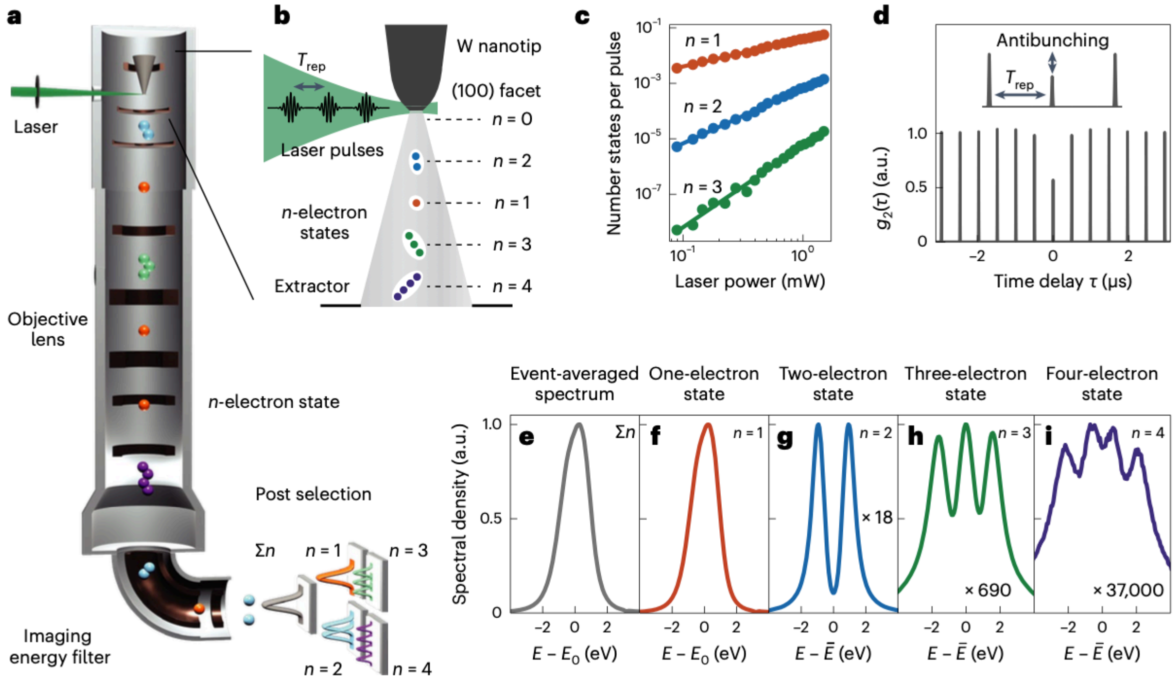

Figure 1 a.) Exemplary experimental setup. Few-electron states are prepared by pulsed photoemission. The electrons pass the sample plane of the microscope and, via post selection, event-based electron spectroscopy enables number-state-selective beam analysis. **b.)** Ultrashort electron pulses are emitted. **c.)** Power scaling of the rates of one-, two- and three-electron states with fitted slopes of 0.99 (*n*=1), 1.99 (*n*=2) and 2.95 (*n*=3) on a double logarithmic scale. **d.)** Second-order correlation function $g_2(\tau)$ of detected electrons with a timing resolution of approximates 10 ns. Inset: the peaks are spaced by the repetition time between laser pulses T_{rep}. The strongly reduced correlation function at zero delay is a clear experimental signature of antibunching. **e-i.)** The event-averaged spectrum **e.)** and separate number-state resolved contributions for *n*=1 (**f.**)), *n*=2 (**g.**)), *n*=3 (**h.**)) and *n*=4 (**i.**)). The two-, three- and four-electron spectra are magnified (see factors in panels) and show distinct shapes with n peaks, indicating discrete energetic separation.

Patent Information

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Publications

Haindl, R. et al. Coloumb-correlated electron number states in a transmission electron microscope beam. *Nat. Phys.* **19**, 1410-1417 (2023). 10.1038/s41567-023-02067-7
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