Aberration-Corrected Quantum Electron Microscopy

M. Turchetti, C-S. Kim, R. G. Hobbs, N. Abedzadeh, K. K. Berggren
Research Laboratory of Electronics, Massachusetts Institute of Technology,
Cambridge, MA 02139, United States.
turchett@mit.edu

P. Kruit
Department of Imaging Physics, Delft University of Technology, Lorentzweg 1,
2628CJ Delft, Netherlands.

Quantum electron microscopy (QEM) is one of the most promising approaches that could overcome the resolution limit imposed by the radiation damage due to the minimum electron dose necessary to surpass shot noise. This is recognized as the main resolution limit when imaging biological specimens.[1] A QEM scheme exploits the concept of interaction-free measurement in a resonant electron optical cavity, whose purpose is to generate and sustain two coupled states of the electron wavefunction, the reference and the sample states.[2]

Here we propose a possible design for this resonant electron cavity, which can be located in conventional scanning electron microscopes. This design is comprised of an electron gate and a tetrode diffractive electron mirror. The first controls the access of the electron in the cavity, while the second acts as a two-state coupler for the reference and the sample states. We initially confirmed electron trajectories using field and axial rays, which are effectively reference and sample beams, respectively, in the electron cavity (Fig 1a). However, this base scheme suffers the presence of strong aberration generated by the tetrode electron mirror. Specifically, aberrations build up with each electron roundtrip, disrupting the electron wavefunction and limiting the achievable resolution.

In this work, we focused on spherical aberration as it has a larger influence on our system. We propose two possible modifications to the initial scheme in order to address this issue. One involves substitution of the electron gate mirror with a hyperbolic triode mirror which generates aberrations of the opposite sign (Fig. 1b).[3] The second one, instead, employs an active correction and involves insertion of a quadrupole-octupole corrector inside the cavity (Fig. 1c). The corrector consists of four multipole elements, on which a superposition of quadrupole and octupole fields is applied to correct the aberrations. We designed and simulated both systems and demonstrated a considerable decreasing in spherical aberration, leading to a better stability of the resonator, which in turn would allow a larger number of roundtrips. Fig. 1d and e show the electron trajectory simulations of the electron beam marginal and paraxial rays (field ray) in the two systems demonstrating a trace stability during resonance below 10 nm in both cases. This could significantly improve the resolution of the QEM system.

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[2] P. Kruit, et al., Designs for a quantum electron microscope, Ultramicroscopy **164**, 31 (2016).

[3] J.P.S. Fitzgerald et al., Adaptive aberration correction using a triode hyperbolic electron mirror, Ultramicroscopy **111**, 1495 (2011).

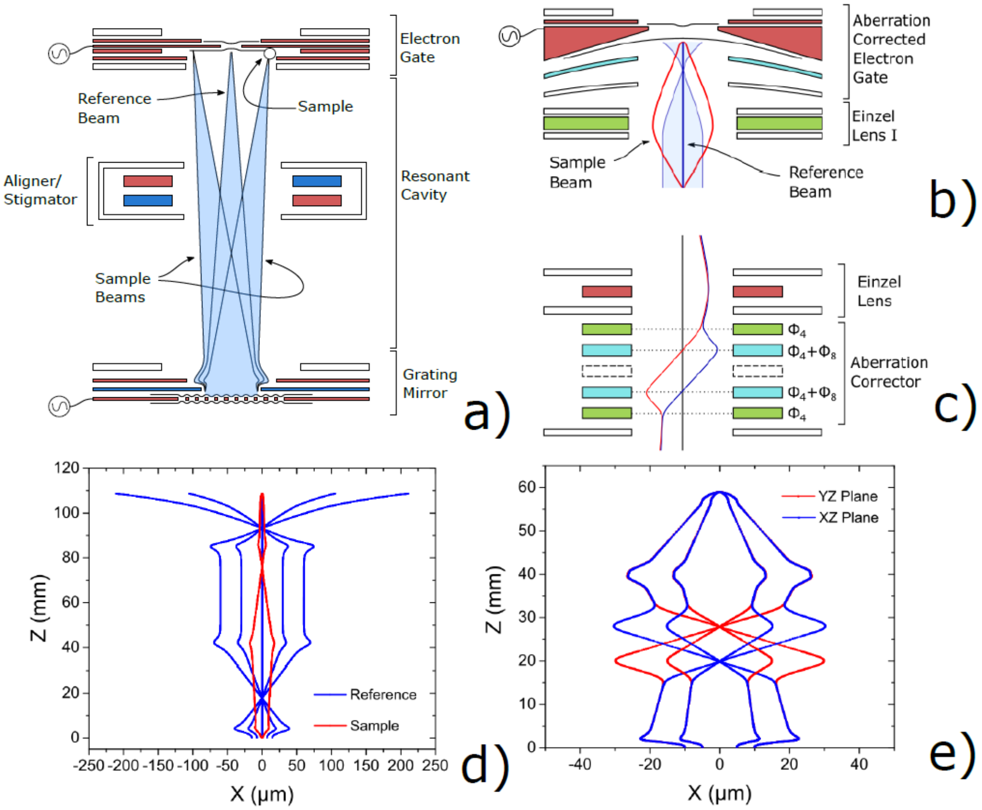

Figure 1: (a) Schematics of the base electron resonant cavity, comprised of an electron gate and a tetrode grating mirror. (b) Sketch of the hyperbolic electron mirror used to substitute the electron gate in order to correct spherical aberration. (c) The same cavity equipped with a quadrupole-octupole spherical aberration corrector. (d) Electron trajectory simulation of both the axial ray of the sample beam and the marginal ray and a paraxial ray composing the reference beam in the resonant cavity where the electron gate has been substituted by a hyperbolic electron mirror. In these simulations, Z is the direction of the optical axis while X and Y are the azimuthal directions. (e) Electron trajectories simulation of the marginal ray and a paraxial ray of the reference beam. The simulation is performed both in XZ and YZ planes as the system, in this case, is not symmetrical.