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Multiphysics Simulation for TEM Objective Lens Evaluation & Design

Patrick McBean[1,2], Zachary Milne[3], Arjun Kanthawar[3], Khalid Hattar[3], Katherine Jungjohann[3], and Lewys Jones[1,2*]

[1.] School of Physics, Trinity College Dublin, Dublin, Ireland.
[2.] Advanced Microscopy Laboratory, Centre for Research on Adaptive Nanostructures & Nanodevices (CRANN), Dublin, Ireland.
[3.] Center for Integrated Nanotechnologies, Sandia National Laboratories. Albuquerque, NM, United States.
* Corresponding author: lewys.jones@tcd.ie

Transmission electron microscopes (TEMs) are used extensively throughout industry and research for exploring down to atomic-scale morphology, composition, and/or the physiochemical landscape of materials. The TEM has experienced recent growth into revolutionary new imaging and experimental methods, such as 4D-STEM, aberration-corrected imaging, and *in-situ* experimentation. Although the TEM is an essential tool for material science, nanoscience, and biological innovation, the current commercial landscape of TEMs risks becoming an oligopoly dominated by a handful of large players, which limits the development of radically new optical geometries. Much of the hesitancy for academics to propose substantial hardware modifications arises from the large purchase price, fear of voiding the warranty/service contract and the fact that many instruments are in shared usage facilities where downtime would be unacceptable. As much of the performance of the TEM is dictated by the specification of the pole-piece within the objective lens [1,2], novel ideas with regards to its design may be fruitful. Nonetheless, the expensive nature of TEMs (even workhorse platforms can cost approximately $1-2M) mean that experimenting with new lens designs may be daunting due to the risk of damaging expensive equipment, and the need for experience in disassembling the TEM column to test novel ideas and realigning it afterwards.

However, several finite element analysis multiphysics simulation software packages exist [3–6], which allow researchers to computationally model and evaluate potential lens designs rapidly and inexpensively. COMSOL in particularly is readily available in many universities and supports the coupling of various separate physics interfaces to perform multiphysics simulations. This offers a simple platform which is accessible to students and non-specialists, but also being powerful enough for serious lens designers to create a ‘virtual twin’ of current electron optics, or to aid in developing new concepts.

By simulating both the magnetic field generated by the lens and the electron path through this field, the effects of changes to the materials or geometry of the lens can be analyzed. This offers a wealth of different parameters to tune for the exploration of alternative designs. An example of these simulations is shown in Figure 1, along with a comparison of the effect of lens excitation on the full width at half maximum (FWHM) of the magnetic flux on the optical axis. This curve suggests an optimal excitation before any increase in FWHM, where the flux is maximized without affecting the FWHM. Having access to these kind of tools allows research to investigate these sort of problems [7,8].

With this work, we aim to outline an intuitive and accessible methodology through which electron optics can be modelled utilizing a ‘virtual twin’ concept. We hope this approach encourages new, creative, and sustainable grass roots innovation to advance TEM capabilities through microscope modification [9].

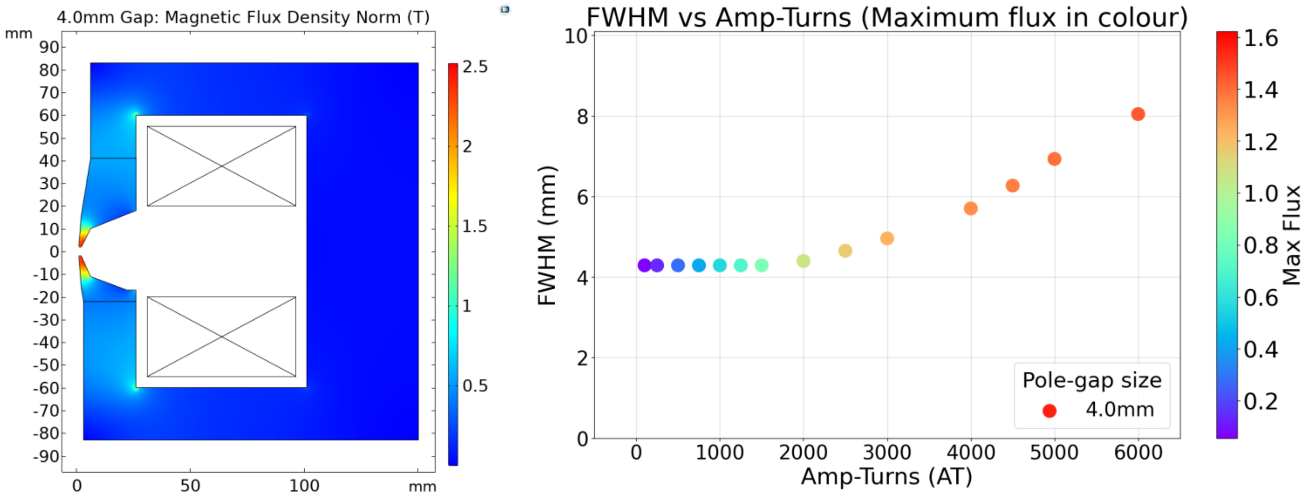

Figure 1. (Left) The magnetic flux density in the objective lens of a TEM. Colormap indicates magnitude of flux. (Right) Comparison of the full width at half maximum (FWHM) on the optical axis at various lens excitations for a gap of 4.0 mm.

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