Nanosecond Pulse Electronics for Gated Electron Mirrors

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One of the major limiting factors of modern electron microscopes is the radiation damage imparted to samples during imaging, which limits the achievable image resolution for many specimens.[1] In recent years, there have been several proposals to improve resolution in biological samples by reducing beam damage with novel measurement schemes based on quantum phenomena. The concepts of interaction free measurement (IFM)[2] and multi-pass electron microscopy[3] are two examples of such proposals. Both designs for accomplishing these schemes can make use of a linear recirculating cavity. This recirculator, which could be inserted into existing microscopes, would allow for either the wavefunction transfer required for IFM or the phase build-up needed for multi-passing. However, in order to achieve these modes, there must be some way to open and close this cavity in a controlled fashion to allow electrons to enter, stably recirculate, then exit the setup.

Our work focuses on creating the structure and electronics required to develop such a recirculator, creating a gated electron mirror. The specifications of the gated electron mirror and its electronics were designed to fit the goals of our collaboration's resonator design: namely creating a highly stable and precise voltage transition between transmitting and reflecting modes of our mirror in a period less than the round trip time of the cavity. Quantitatively, this requirement corresponds to injecting a 100-volt pulse with less than 10 ns rise time into a capacitive, highly resonant kilovolt-biased load, to achieve a transition with less than 1% error at the time of the first reflection and beyond.

These criteria were achieved by using gallium nitride transistors designed with vacuum-compatibility in mind so that they can be placed directly at the gated mirror, as illustrated in Fig. 1. The proximity will be beneficial as it will help to avoid issues with impedance matching and vacuum feedthroughs for high voltage electron optics, and allows for the reduction of the effective gate capacitance and inductance and thus faster transitions. In order to minimize voltage ringing, custom vacuum-compatible filters and bias tees were also designed and tested with this structure. An example voltage trace of this circuitry is shown in Fig. 2. While the application of this design is currently specific to our project, the ability to precisely and inexpensively control relativistic charged particles in laboratory-scale environments may have application in related fields.

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[1] Egerton, R. F., *Ultramicroscopy* 127 (2013): 100-108.
[2] Kruit, Pieter, et al., *Ultramicroscopy* 164 (2016): 31-45.
[3] Juffmann, Thomas, et al., *Scientific reports* 7.1 (2017): 1699.

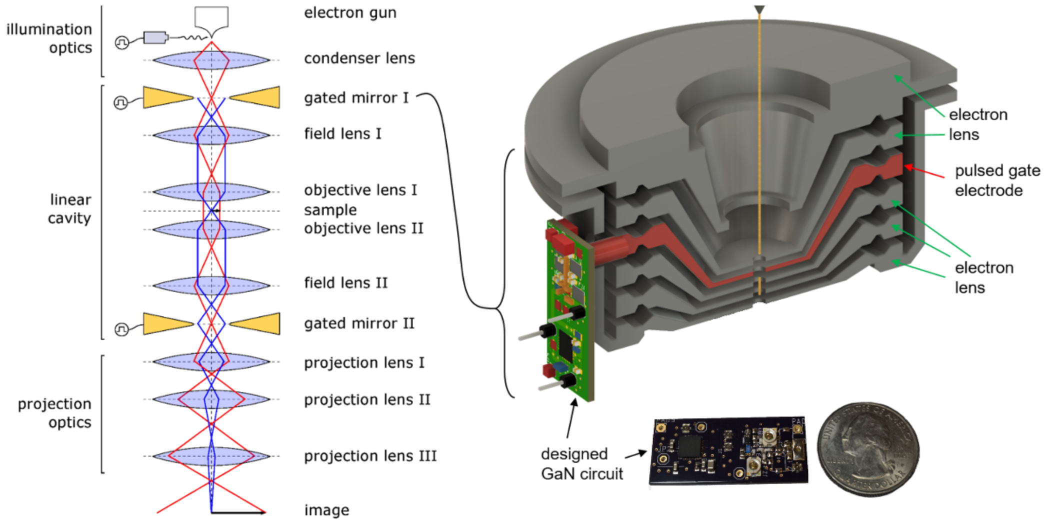

Figure 1: Designs of an electron recirculator with electron mirror and circuit board for context. Two gated mirror structures are to be placed at the top and bottom of the cavity shown to the left, and the ability of each mirror to rapidly and controllably open and close is crucial to the success of this scheme. To the right, we have a cross-section of the gated electron mirror structure, with the pulsing circuit is placed in vacuum directly next to it in order to optimize rise times and minimize ringing. This circuit is approximately the size of a quarter, and further iterations will shrink this design further.

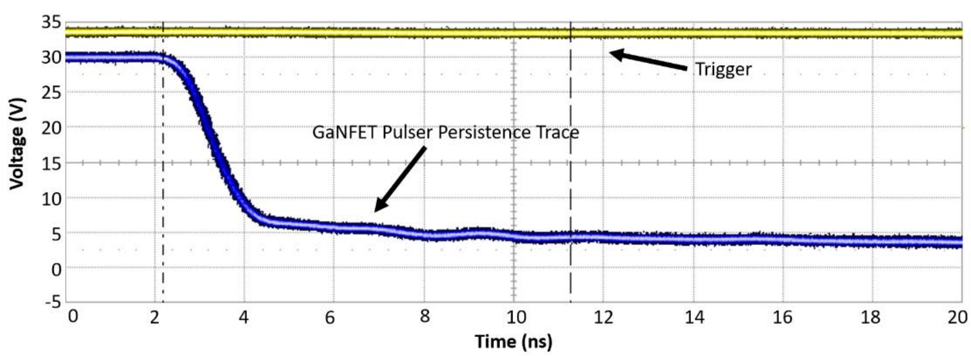

Figure 2: Direct circuit trace of the GaNFET circuit into a highly resonant simulated 50pF load. The maximum voltage transition measured directly so far was only 25 volts due to limitations of the probe and oscilloscope used, but the circuit is capable of and has been tested going up to 200 volts. Notice the small amount of ringing, which is due to the "worst-case" resonance of our gated mirror structure. This load was designed to resemble the gated mirror structure as a first check before attempting to gate the actual mirror, which has not yet been integrated in vacuum with the pulsing circuit.