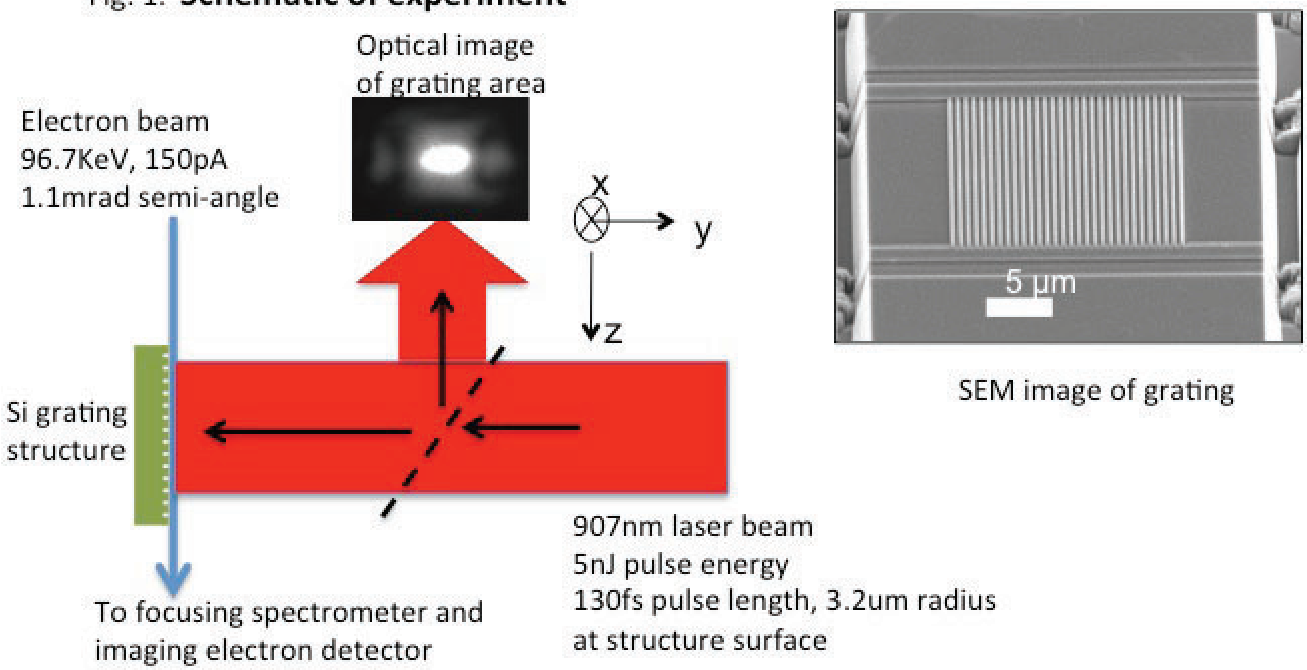
Microstructure-Induced Laser Acceleration of Free Electrons

Ken Leedle[1], James Harris[1], Robert Byer[2], Fabian Pease[1]
[1]Department of Electrical Engineering, Stanford University, CA 94305, USA
[1]Department of Applied Physics, Stanford University, CA 94305, USA

The idea of replacing RF electric waves with light for bunching electron beams goes back several decades and includes the use of plasmas as an interaction medium (the 'wakefield' process) . More recently E. A. Peralta, et al., (Nature 503, 91 (2013)) and J. Breuer and P. Hommelhoff, (Phys. Rev. Lett. 111, 134803 (2013)) have described the use of microstructures (gratings) for bringing about optical acceleration and deceleration of electron beams. The key to success is to induce extremely high fields concentrated at the beam. Very recently we reported that a silicon microstructure has been effective (because of the very high induced fields) as an interaction medium in bringing about longitudinal acceleration, deceleration and deflection, (Leedle et al. Optica, accepted for publication January 2015) and here we describe the apparatus and experimental procedure and will present some more recent results and discuss applications. The apparatus (fig. 1) includes a 100KeV electron beam column employing a LaB6 source and 2 magnetic electron lenses which direct a beam of up to several nA, semi-angle of convergence of 1mrad, along the surface of the silicon microstructure. The beam then enters a magnetic 90-degree sector electron spectrometer and thence to an imaging CMOS electron detector. A 'knife-edge' is used to cut off electrons so that only those that have been accelerated by more than about 245eV reach the imaging detector. The 907nm light beam is generated by a Ti-sapphire laser and is brought through a window and directed normally to the surface of the silicon microstructure. Because of the nature of the silicon material and the ribbed shape of the microstructure the local accelerating fields, for a 5nJ, 130fs light beam, reach 200MV/m. This is about an order of magnitude higher than those obtained by Breuer and Hommelhof. An outline of the mechanism is shown in fig. 2. The results (fig. 3) are positive. Acceleration of electrons to more than 1000eV are observed. In this case the fraction of electrons accelerated significantly (beyond 245eV) is very small (about 1 in 1e4) because of the low duty cycle of the laser and the simple and restricted geometry (15um length, but only a 5.6um interaction length) of the microstructure. The use of a pulsed electron source is an obvious improvement to be made. At present many electrons are also deflected laterally and, obviously, we are limited to observing those that are acted on by the accelerating phase of the light wave (observing the retarded electrons would be less convincing because any electrons scattered off solid surfaces would also be observed). One straightforward modification of the microstructure would be to increase the interaction length, say, from the present 15um to maybe 10mm and chirp the period of the grating. To minimize lateral deflection we could employ more sophisticated structures and bring in light from both sides. Achieving significant chopping over only a small fraction of the light phase would allow pulses in the single fs range and hence open the way for very highly time-resolved diffraction, electron microscopy and other experiments.

Fig. 1. **Schematic of experiment**



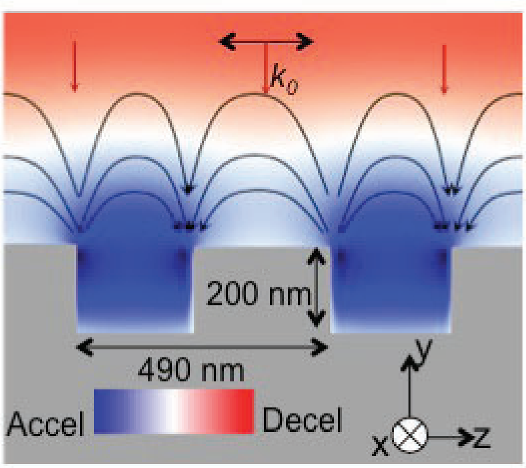


Fig. 2 Results from FDTD analysis showing accelerating electric fields at one instant. Electrons closest to the grating are being (positively) accelerated. By synchronizing the electron transit time between grating bars with the optical phase some electrons in a continuous beam will receive net acceleration.

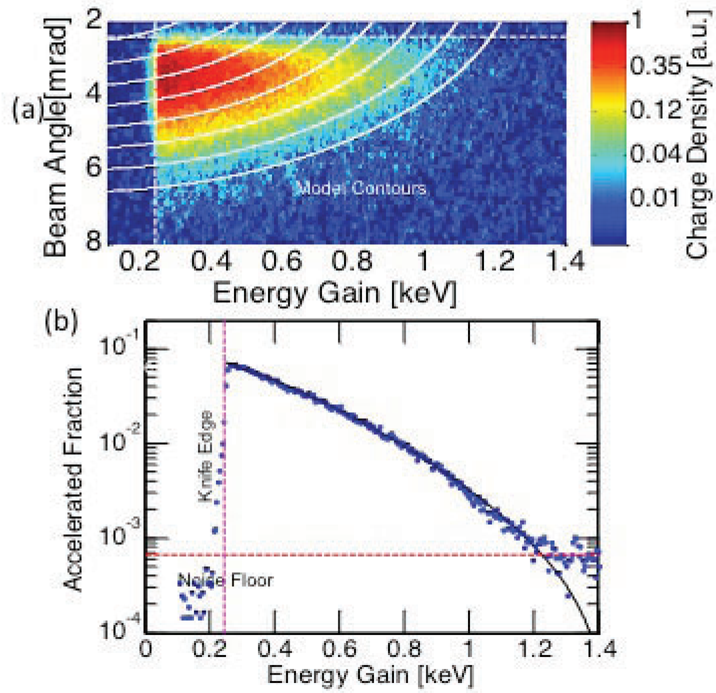


Fig 3 (a). Spectrum image accumulated over 200s for a 2.4 mrad cut-on angle spectrometer offset. Multiply-scattered electrons and x-rays generate a uniform background noise level over the entire spectrum. Charge density contour lines from our model are superimposed on the spectrum. Energy and angle resolution are 4.5eV and 82 mrad per pixel, respectively. (b) Accelerated fraction I_{acc}/I_{eff} as function of energy gain for the raw spectral data and model fit. From Leedle et. al. Optica, Accepted for publication January 2015.