

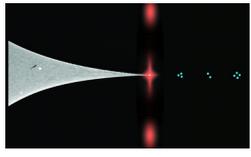
Applications of a Femtosecond Electron Point-Source

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Concept:

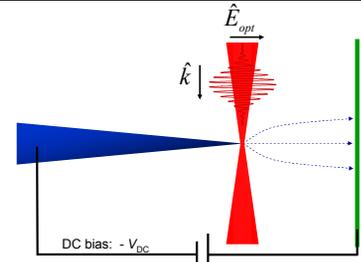
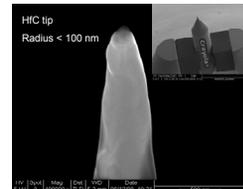
Trigger a sharp field emission tip with a fs laser.

- nm source size
- high brightness
- fs time resolution
- coherent electrons
- tabletop system

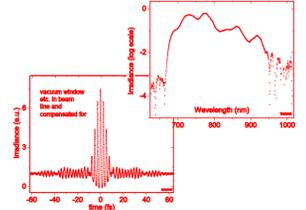


Setup:

- Cold-cathode field emission tip**
- Radius r_{tip} 20 to 150 nm
 - Electrochemically etched
 - Tungsten (work function 4.5 eV)
 - Hafnium Carbide (3.5 eV)



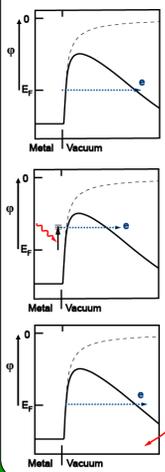
- Ultrashort laser**
- Titanium sapphire
 - Pulse duration < 10 fs
 - Rep rate 150 MHz
 - Average power ~ 100 mW at tip



Microchannel Plate Detector MCP

- Tip imaged with magnification $\sim 10^5$
- Single-atom resolution possible by field ion microscopy method
- Single-electron detection, Gain $\sim 10^6$

Physical Principles:



DC emission

- Apply large field (GV/m) to surface using sharp tip as a lightning rod
- Electrons tunnel through barrier
- Emission current is extremely nonlinear in the DC bias voltage

Photo-field emission

- Electrons in the metal are excited by the laser (absorption of one or more photons)
- Effectively, work function ϕ is reduced
- Dominant at low laser power
- Emission is function of pulse ENVELOPE

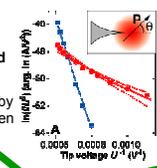
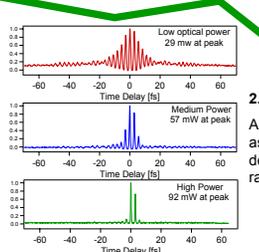
Optical field emission

- The laser's electric field directly modulates the barrier for correct polarization
- Dominant at high laser power
- Emission current is a function of laser FIELD

Key Results:

1. Photo-field emission observed

Fowler-Nordheim plot reveals effective work function decreased by 1.5 eV with low-intensity in Tungsten

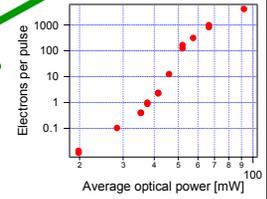
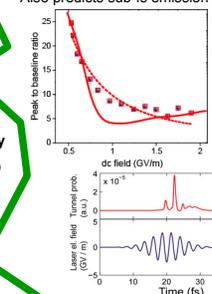


2. Huge tunable nonlinearity

Autocorrelation traces with tip as nonlinear-response detector, peak-to-baseline ratios > 1000 observed.

3. Optical field emission inferred (Tungsten)

- Numerical integration of Schrodinger eqn. agrees with nonlinearity vs. dc bias data
- Also predicts sub-fs emission timescales



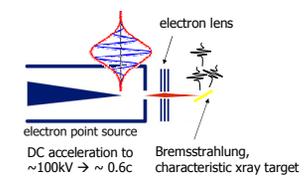
4. High emission current in HfC

If emission timescale is < 100 fs, peak current densities emitted are $> 10^9$ A/cm²

Applications:

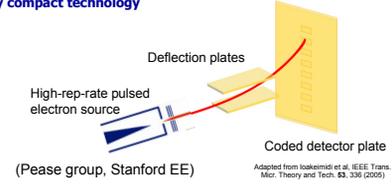
Ultrafast xray source

- Orders of magnitude advance in timing resolution over state-of-the-art.
- Extremely high peak brightness
- Tiny footprint (< 0.5 m²)



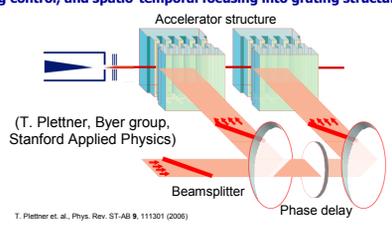
Analog-to-digital conversion

- Jitter of sampling electrons currently limits performance to 2 GS/s, 8 – 10 bit, or with cryogenics (5 K) 20 – 80 GS/s, 12 bit
- Jitter < 100 fs with optical field emission; 100 GS/s, 12 bit may be possible
- Very compact technology



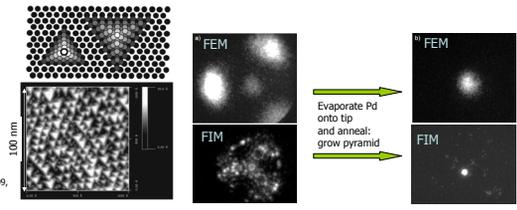
Electron source for laser accelerator

- Grating accelerator structure accelerates or decelerates electrons depending on electron timing with respect to laser phase
- 10 GeV/m accelerating gradients theoretically possible
- Optical field emission source provides necessary high brightness, precision timing control, and spatio-temporal focusing into grating structure



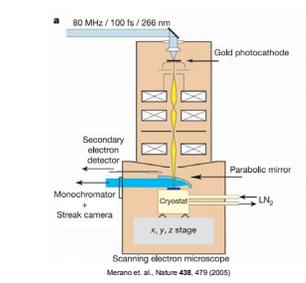
Electron-on-demand

- Single-atom emitter
- Topmost atom on pyramid has localized states with long (5 fs) lifetimes
- Emission timescale $<$ lifetime \Rightarrow sub-poissonian emission current?



Ultrafast electron microscopy

- Spatial resolution < 1 nm
- Temporal resolution < 10 fs?

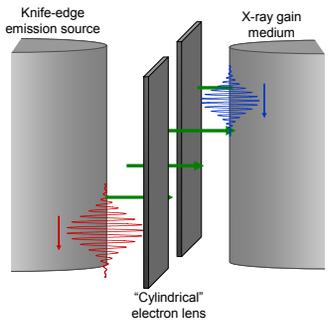


	Today's technology (Merano et al.)	Our proposal
Method	Photoelectric effect	Optical field emission
Brightness	$\sim 10^3$ A/cm ² sterad	$> 10^6$ A/cm ² sterad
Spatial resolution	10 – 50 nm	< 1 nm
Timing resolution	10 ps	< 100 fs ... < 1 fs?

Nien et al. PRB 2009, Fu et al. PRB 2001

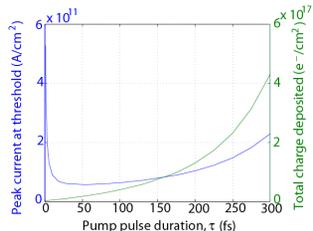
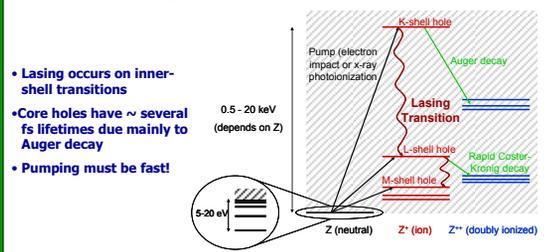
Extension: Line Source, Xray Laser:

X-ray laser concept: traveling wave optical field emitter



- Ultrafast, coherent x-rays
- Huge peak brightness
- Tabletop source!
- Optical field emission is the enabling technology
- Requires 10^{11} A/cm² current density at gain medium for lasing

X-ray laser energy level diagram



- Material damage is of concern
- Pump pulse should be \sim same duration as K-hole lifetime