Laser triggered ultrafast electron emission from a sharp tungsten tip

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Idea
Trigger electrons from field emission tip with a (low-power) femtosecond laser:
- nanometer source size (down to single atom)
- femtosecond time resolution

Setup
Laser: Nanolayers Ventome 1
Laser parameters: 
- 810nm, 150 MHz, 1W, 8fs pulse length
- Focused with gold mirror to Tip: 11.8μm

- Peak intensity ~ 10^12 W/cm^2
- Peak electric field strength ~ 2 GV/m
  (with AC field enhancement due to tip)

Basics of field emission (no light yet)
Apply large field to a metal-vacuum interface: tunnel barrier.
Current density j given by field F and workfunction Φ through Fowler-Nordheim equation:

\[ j = \frac{e^3 F^2}{8\pi\hbar\Phi^2(v)} \exp\left[ -\frac{8\pi^2 m\Phi^3/2}{3\hbar e F v}\right] \]

Laser induced emission
Two processes, depending on field strength:

Photo-field emission:
- Laser effect: reduced effective workfunction: Φ_{eff} = Φ - hv
- One photon effect: photoemission linear in laser power; probability of electron emission depends on laser pulse envelope.

Optical field emission:
- Laser effect: barrier wigged
- Highly non-linear effect of field on emission current (only field component parallel to tip plane contributes); probability of electron emission depends on the laser electric field.

Key experimental results:

1. Bias voltage dependence:
   - Autocorrelation trace of laser pulse measured with tip as nonlinear detector provides a simple measure of the nonlinearity.

2. Carrier-envelope phase dependence:
   - Optical field emission
   - CE Phase dep.
   - Experimental modulation depth
   - \( \gamma \approx 3 - 5 \)

3. Numerical model for the intermediate regime:
   - Numerical integration of the Schrödinger equation predicts sub-optical cycle (sub-femtosecond) emission times.
   - It also provides a reasonable fit to nonlinearity vs. DC bias measurements and explains the null carrier envelope phase dependence result.

Applications:

Deterministic current source
Proposal: use single atom field emitters in laser emission mode

Ultrafast x-ray source
- Demonstrated in other groups using electron source based on the photo-electric effect
- Optical field-emission based electron source should have better spatial and temporal resolution.

Electron source for laser accelerator
- Ultrafast electron microscopy
- "Extremely high-resolution electron microscopy at high current density" (2D imaging of sub-atomic spatial periodicities)
- "Fast and direct" (200 fs ago, different time scale)

An electron is accelerated or-asymmetrical depending on its timing relative to the phase of the laser field.

Analog-to-digital conversion
(Prof. group, EE)
- Jitter of sampling electron pulse train is a limiting factor
- 100 Gsec, 12 bit ADC with ultra-high repetition rate source