We gratefully acknowledge financial supports from NSRRC, CSIST, NSC, and NTHU.
Outline

• Facility Overview

• Sketch of Programs

• Future Perspectives
HOPE Laboratory Building

- A 4-story building with a total area of 13,000 ft². (350坪、1,155 m²)
- Dedicated to advanced particle acceleration and radiation.

Low & Intermediate-energy Laser Lab

Others under planning

High-energy Laser Lab
Nano-, μ-Fab Cleanroom

Accelerator/FEL Facility
Collaboration Network

NTHU/CSIST/NCU

International Collaborators

Stanford U. (equipment contributor)
Tel Aviv U. (superradiance FEL)
Russia Academic of Science (High power microwave)
CSIST (high power microwave)
NSRRC (photoinjector, FEL)
NTHU team

Domestic Collaborators

NSRRC

羅國輝 (Gwo-Huei Luo, NSRRC)
劉偉強 (Wai-Keung Lau, NSRRC)
樊台清 (Tai-Ching Fan, NSRRC)
林劉恭 (Kung LinLiu, NSRRC)

黃衍介 (Yen-Chieh Huang, NTHU)
林凡異 (Fan-Yi Lin, NTHU)
林彥穎 (Yen-Yin Lin, NTHU)
楊士禮 (Sidney S. Yang, NTHU)
陳銘 (Ming Chen, NTHU/CSIST)
陳彥宏 (Yen-Hung Chen, NCU)

(Halloween photo)
Fourth Floor

- Advanced Teaching Lab
- Low & Intermediate Energy Laser Lab
- Scholar/student offices
- Small meeting room
- Conference room
- Small meeting room
Sketch of On-going Programs

1. S-band THz-pulse-train Photoinjector
   (collaborating with 劉偉強、李安平、羅國輝 of NSRRC)

2. TW-power, THz-pulse-train laser
   (collaborating with 劉偉強 of NSRRC)

3. Superradiance Free-electron Laser (FEL)
   (1) MW Desktop superradiance THz FEL
       (collaborating with 劉偉強 of NSRRC)
   (2) mW miniature superradiance THz Smith-Purcell FEL
       (collaborating with 樊台清、林劉恭 of NSRRC)

4. GW X-band relativistic backward-wave oscillator
   (collaborating with CSIST)
THz-pulse-train Photoinjector

1.6-cell S-band photocathode electron gun

Exciting plasma wave
plasma-wave accelerator

TW-power, THz-pulse train laser

Superradiance FEL

Density-modulated electrons

Photocathode gun

High-power test
TW-Power, THz-pulse-train Laser System
(10 Hz and GHz pulse-train are also available)

15 ps

1-0.1 ps

To be commissioned Spring 2009.
Radiation from a single electron

Radiation spectral energy

\[
\left( \frac{dW}{d\omega} \right) = \frac{\mu_0 c \omega^2 q^2}{16\pi^3} \int_\infty^\infty \int_\infty^\infty \left( e^{j\omega(t-\hat{n}\cdot\vec{r}/c)} \hat{n} \times \vec{\beta} \right) dt \left| \dot{d}\Omega \right|^2
\]

- \( W \): radiation energy
- \( \omega \): radiation frequency
- \( \mu_0 \): vacuum permeability
- \( q \): charge
- \( t \): time variable
- \( \Omega \): solid angle
Undulator Radiation

For undulator with period $N_u$

\[
\frac{dW}{d\omega} \propto \text{sinc}^2[2N_u(\omega/\omega_r - 1)]
\]

Synchronism frequency

\[
\omega_r = 2\pi c \left[ \frac{1 + a_u^2}{2\gamma^2 \lambda_u} \right]^{-1}
\]

Undulator parameter

\[
a_u = 0.093B_{rms} \text{ (kgauss)} \times \lambda_u \text{ (cm)}
\]
Condition for constructive interference

\[
\frac{\Lambda_g}{c \beta} \cdot c - \Lambda_g \cos \theta = m \lambda \Rightarrow \lambda = \frac{\Lambda_g}{m} \left( \frac{1}{\beta} - \cos \theta \right)
\]

\[\beta = \frac{v_e}{c}, \gamma = \frac{1}{\sqrt{1 - \beta^2}}\]

For large \(\gamma\) and small \(\theta\),

\[\lambda \sim \frac{\Lambda_g}{m} \left( \frac{1}{2 \gamma^2} + \frac{\theta^2}{2} \right)\]

\(\lambda\): wavelength
\(\Lambda_g\): grating period
\(c\): vacuum wave velocity
\(v_e\): electron velocity
\(m\): integer
Radiation from many electrons

\[
\left( \frac{dW}{d\omega} \right)_N = \left( \frac{dW}{d\omega} \right)_1 \left| \sum_{i=1}^{N} e^{-jk \cdot r_i} \right|^2
\]

View at a constant time

\[
\Rightarrow \left( \frac{dW}{d\omega} \right)_1 \left| \sum_{i=1}^{N} e^{-j\omega t_i} \right|^2
\]

View at a constant location

\[ r_i : \text{position of } i^{\text{th}} \text{ electron} \]
\[ k = 2\pi/\lambda_r : \text{wave number} \]
\[ \lambda_r : \text{radiation wavelength} \]
\[ N : \text{number of electrons} \]

\[
\left| \sum_{i=1}^{N} e^{-j\phi_i} \right|^2 = \begin{cases} 
\sim N & \text{for random phase } \phi_i \\
N^2 & \text{for a constant phase } \phi_i = \phi_0 \end{cases}
\text{ superradiance}
\]
Superradiance from an electron bunch train

Analogy in grating diffraction
Desktop THz Superradiance FEL
(space-charge force making a THz SASE FEL difficult)

**Comparison: PEGASUS FEL** (P ~300 kW @ 2 m with gamma = 35, \( \lambda = 13 \ \mu\text{m} \), I\(_{\text{peak}}\) = 134 A…)

**UCLA - under construction**
Infrared Free-Electron Laser. The space charge forces prevents saturation within the 2m undulator length.
ASTRA Simulation

rms beam size

Solenoid field

Normalized beam emittance

B_{z, peak} = 3 \text{ kG}
**Beam Parameters**

- Mean Energy: 6.3 MeV
- rms Energy spread: 0.3%
- Initial Beam radius: 0.15 mm
- Beam emittance: $5.3\pi\text{mm mrad}$
- peak current: 100 A
- Initial bunching factor: 0.2

**Helical Undulator Parameters**

- Undulator period: 1.5 cm
- Undulator type: helical
- Undulator parameter: 0.82
- Section length: 1 m
- Resonant wavelength: 76 μm (3.94 THz)
Bunching from FEL buildup

Debunching from SC force

~100 cm

~120 cm

~60 cm

~20 MW Desk-top THz FEL
**Miniature THz Smith-Purcell FEL**

Power enhancement factor $\sim 10^{4-6}$ (!) from the pre-bunched beam

Smith-Purcell Gratings

Ruled by a dicing saw at NTHU

Lithographically fabricated by 林劉恭、樊台清 *et al.* of NSRRC
Future Perspectives

1. Laser-driven Particle Acceleration

For \( n_e = 10^{18}/\text{cm}^3 \),
\[ E_z \sim 100 \text{ GV/m or } 1 \text{ GeV/cm!} \]

\[ C \tau_p \sim \lambda_p \]

Plasma wavelength \( \lambda_p \sim 50 \mu \text{m} \)

2. Compact x-ray Sources

X-FEL

Plasma-wave accelerator

Laser synchrotron/FEL

Hard x-ray @ 1 Å

25 MeV beam

5 m

~20 MHz

RF gun
The NTHU High-energy OPtics and Electronics Laboratory (HOPE Lab)

Openings for postdocs and PhD students
Contact info: ychuang@ee.nthu.edu.tw
4th Asia Summer School & International Symposium on Laser-plasma Acceleration and Radiation

Summer, 2009
National Tsinghua University
Hsinchu, Taiwan

Laser pulse

\[ E \sim 100 \text{ GV/m}! \]

Laser pulse train
THANK YOU FOR YOUR ATTENTION