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⇒ Overview of SR and CHESS

⇒ Why using SR for nanostructures, and types of information obtained

⇒ Systems:  Si (001) nanostructures
SiO₂/Si (001) columns
• InGaAs/GaAs QWRs
  Self-assembled InGaAs QDs
• ZnMnTe/ZnTe epilayers

⇒ Recent works by other groups

⇒ Future Interests
Growth in Synchrotron Radiation Science

INSPEC: Synchrotron Radiation (not astronomy)

Protein Data Bank: Deposits / year

September 2001
Synchrotron Facilities

~ 70 storage-ring based synchrotron facilities worldwide

A. Hopkirk at Daresbury Laboratory, UK, http://srs.dl.ac.uk/SRWORLD/index.html
Cornell High Energy Synchrotron Source (CHESS)

- 6 beam lines, 12 stations
- 8 scientists, 19 support staff
- NSF funding $3M/year
- MacCHESS $1.8M/yr NIH
- No CATs / PRTs
- Cornell G-line

Cornell University
Ithaca, New York
High X-ray Flux from Wigglers

G-line Wiggler:
designed & fabricated in house by K.D. Finkelstein at CHESS
Usage at CHESS

CESR: 5.3 GeV, 350 mA

Year 2000
Running time: 171 days
Number of users: 594 users

Scientific Fields (2000)

- biology/biophys: 45%
- physics: 11%
- x-ray science: 14%
- materials science: 27%
- other: 3%

A1, F1, F2: protein crystallography
A2: high-energy diffraction, thin-film growth
B1: high pressure, energy-dispersive
B2: EXAFS, angle-dispersive high pressure
C1: diffraction physics
D1: SAXS, imaging
F3: general diffraction
G1: SAXS
G2: grazing incidence scattering
G3: thin-film growth
Structural Biology


Yonath et al., Weizmann Inst., Israel (2000)
Real-time Crystal Growth

Ion-assisted MOCVD growth of GaN on sapphire.
Headrick et al., PRB 58, 4818 (1998)
Time-Resolved X-ray Imaging

- Imaging of diesel fuel spray
- With μs time resolution
- Pixel Array Detector (PAD)
- Liquid-gas mixture core
- Ultrasonic shock wave
- Near-nozzle region imaging

Wang et al. (APS, 2001)
Gruner et al. (CHESS)
Study of Nanostructures

**Nanostructures**: 1-100 nm
- semiconductors
- magnetic
- organic polymers

**Basic Information**:
- Size
- Shape
- Internal structure (strain)
- Buried structure

InGaAs / GaAs

Si (001)

Ge / Si
Technical Challenges

Experimental Methods:

- TEM
- XRD

nondestructive

Technical challenges:

- Signal to background?
- Particle size broadening?
- Strain variation?
Use of Synchrotron Radiation

**Advantages:**

- **high intensity:** \( I_0 \sim 10^{11}-10^{13} \text{ ph/s/mm}^2 \)
- **narrow divergence:** \( \Delta \theta \sim 2-10 \mu \text{rad} \)
- **high coherence width:** \( L_{coh} = \lambda D/s \sim 10-100 \mu \text{m} \)
- **tunable wavelength:** element specific
Basic Concept in XRD

**Size Effect:**

$$\Delta Q \sim \frac{1}{L}$$

Real space

Reciprocal space

$$\Delta Q = \text{independent of } |Q|$$

**Strain Effect:**

$$\Delta Q = -|Q| \frac{\Delta a}{a}$$

$$\Delta Q = |Q| \Delta \theta$$

$$\Delta Q \propto |Q|$$
Advanced XRD Techniques

⇒ Reciprocal space mapping
⇒ Grazing-incidence diffraction
⇒ Coherent Grating diffraction
⇒ Crystal truncation rod (CTR)
Overhead Projector …..
Information that can be obtained ...

⇒ Correlation length / lateral periodicity

⇒ Size and shape information: width, height, side-wall slope, ...

⇒ Imperfections: inhomogeneities, defects, ...

⇒ Time-resolved: changes during annealing, ...

⇒ Superlattice orientation: w.r.t. substrate crystal lattice

⇒ Strain in nanostructures: average strain
   strain variation (gradient)
   longitudinal $\partial a_x/\partial x$
   transverse $\partial a_z/\partial x$
Oxidation of Si (001) Pillars

SiO₂ / Si (001)

Tensile strain in Si (001) pillars due to 6 nm thick SiO₂

⇒ Δa∥/a∥ = 4×10⁻⁴
Recent Work by Others
Kegel et al. PRL (2000)

Nanometer-Scale Resolution of Strain and Interdiffusion in Self-Assembled InAs/GaAs QDs
Recent Work by Others
Wiebach et al. PRB (2000)

Strain and Composition in SiGe Nanoscale Islands

\[ I(q) \propto \sum_k \left| F_k(q) e^{i (r_k + u_k)} \right|^2 \]
**Elastic Strain:** \( \{ \sigma \} = \{ C \} \{ \varepsilon \} \)  

Hook’s Law

- **External:**
  - external pressure
  - lattice mismatch

- **Intrinsic:**
  - microscopic nature
  - exchange striction
Future Interests

⇒ Nanoperiodic structures by strain-controlled etching
  Melissa Hines and Stephen Sass (Cornell)

⇒ Nanoscale magnetic domains of CMR materials
  Yuri Suzuki (MSE, Cornell)

⇒ Self-assembled organic nanostructures
  with Wang Chen et al. (Inst. Chem., Beijing)
X-ray Interactions with Matter

- **Absorption**
  - $E \rightarrow e^-$
  - => spectroscopy

- **Scattering**
  - $E, k \rightarrow E', k'$
  - => elastic $E' = E$
  - => inelastic $E' \neq E$

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