방사광 가속기 연구소
Soft X-ray/VUV Program 소개

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오늘에 이야기

포항 방사광 가속기의 *soft X-ray/VUV program*

방사광 가속기의 중요 *parameters*와 의미

.Flux

.Current

.Time structure

. ……

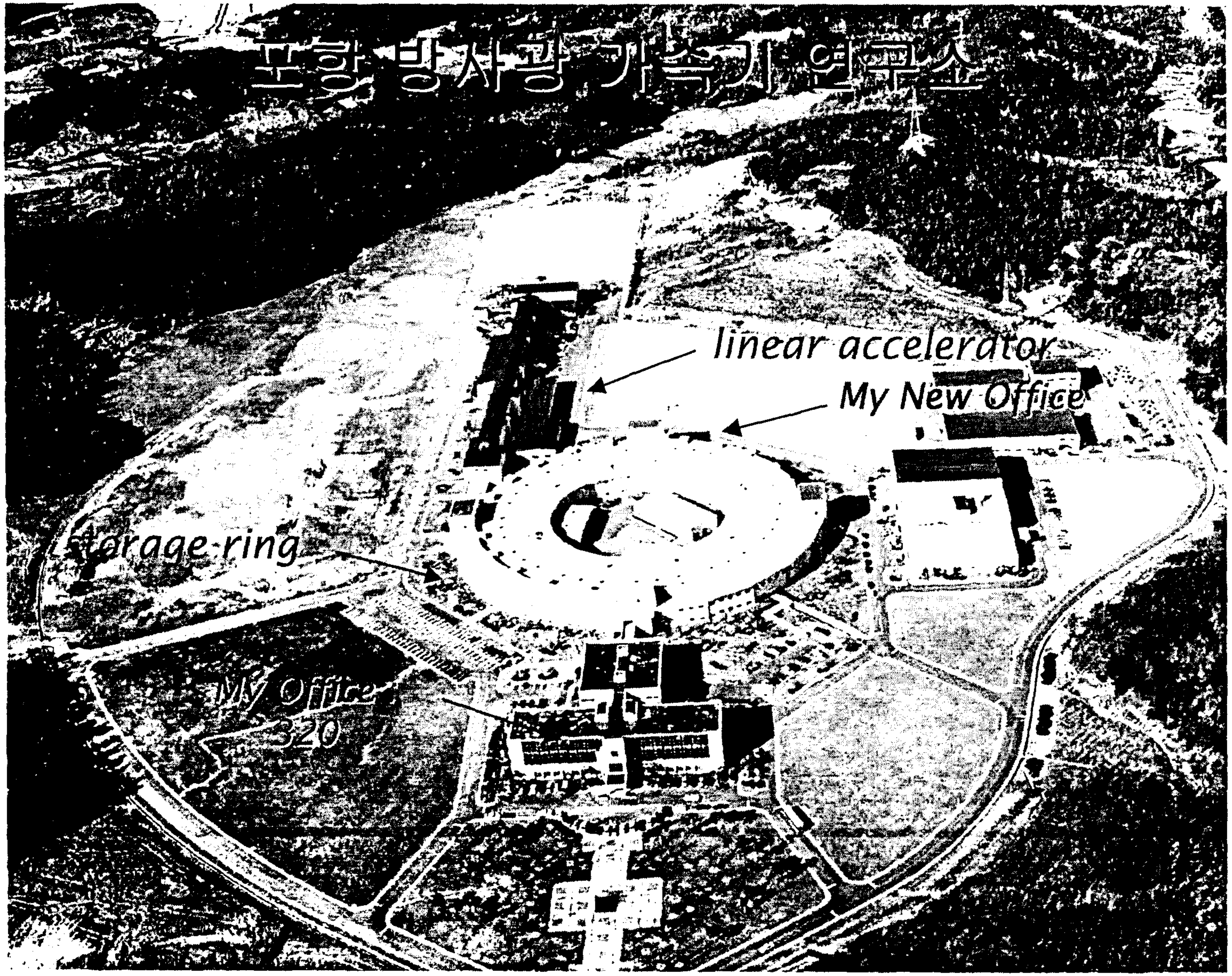
포항 방사광 가속기의 *soft X-ray/VUV program* 소개

.Beamline 소개

.연구 결과 소개

PAL

Pohang Accelerator Laboratory



Linac(선형가속기)

.Beam species : electron

.Beam Energy : 2 GeV

.Total length : 150 m

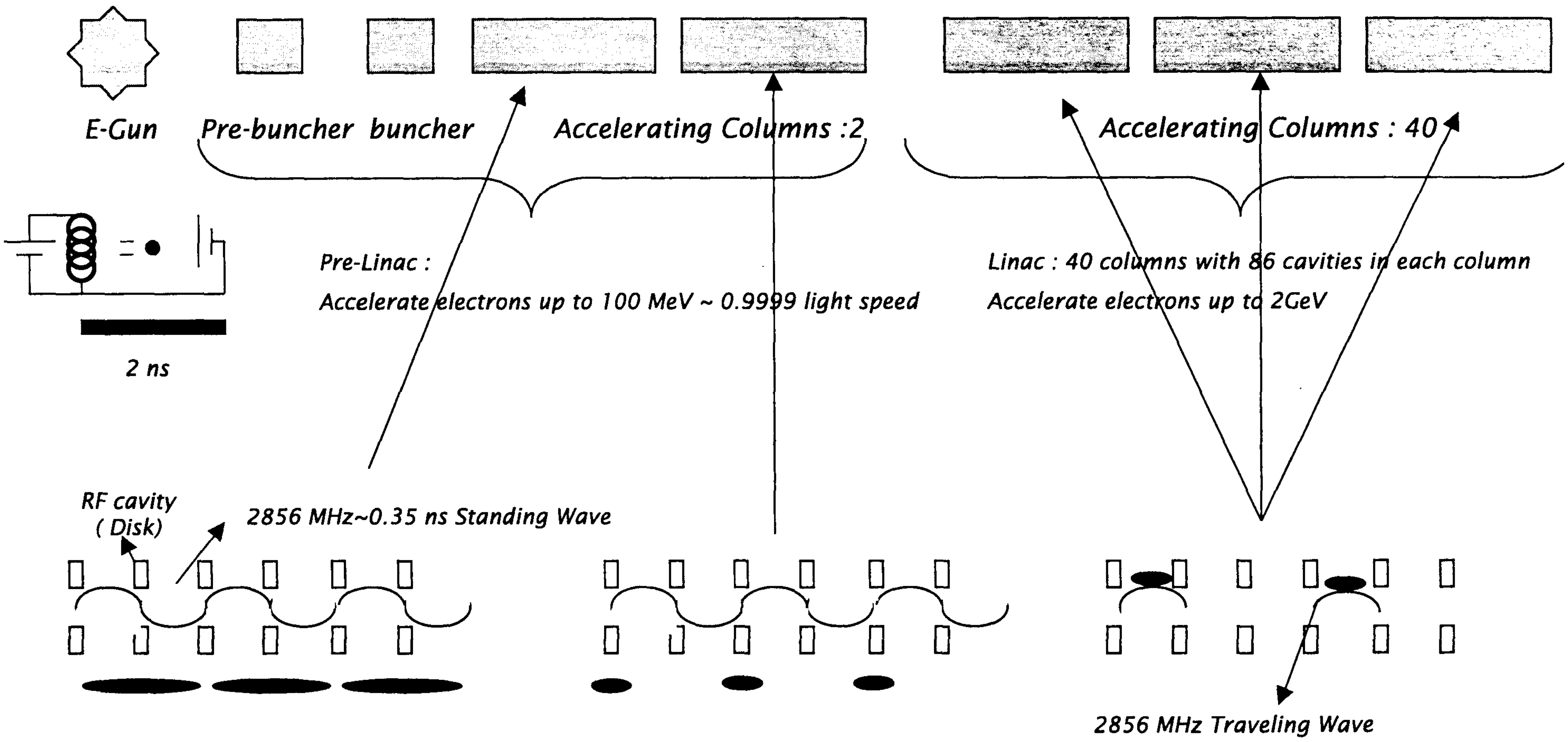
.# of column : 42

.# of cavities in a column : 86

.operating frequency : 2,856 MHz

Linac(선형가속기)의 간단한 원리

(Surfing Electrons with Microwave)



E-Gun

Pre-buncher buncher

Accelerating Columns :2

Accelerating Columns : 40

2 ns

Pre-Linac :
Accelerate electrons up to 100 MeV ~ 0.9999 light speed

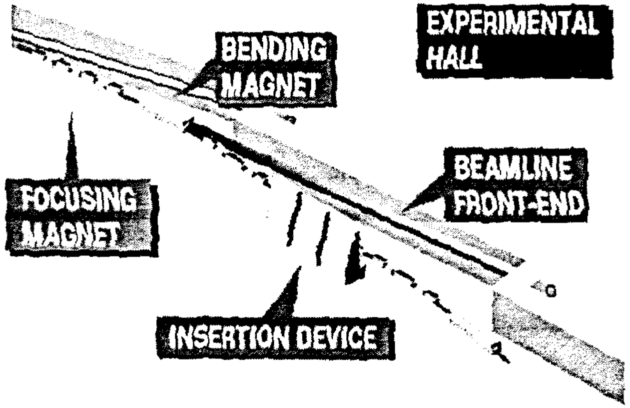
Linac : 40 columns with 86 cavities in each column
Accelerate electrons up to 2GeV

RF cavity
(Disk)

2856 MHz~0.35 ns Standing Wave

2856 MHz Traveling Wave

Storage Ring (저장링)



.Natural Emittance : 18.2 nm.rad

.Beam Energy : 2.0/2.5 GeV

.Natural Bunch Length : 5 mm

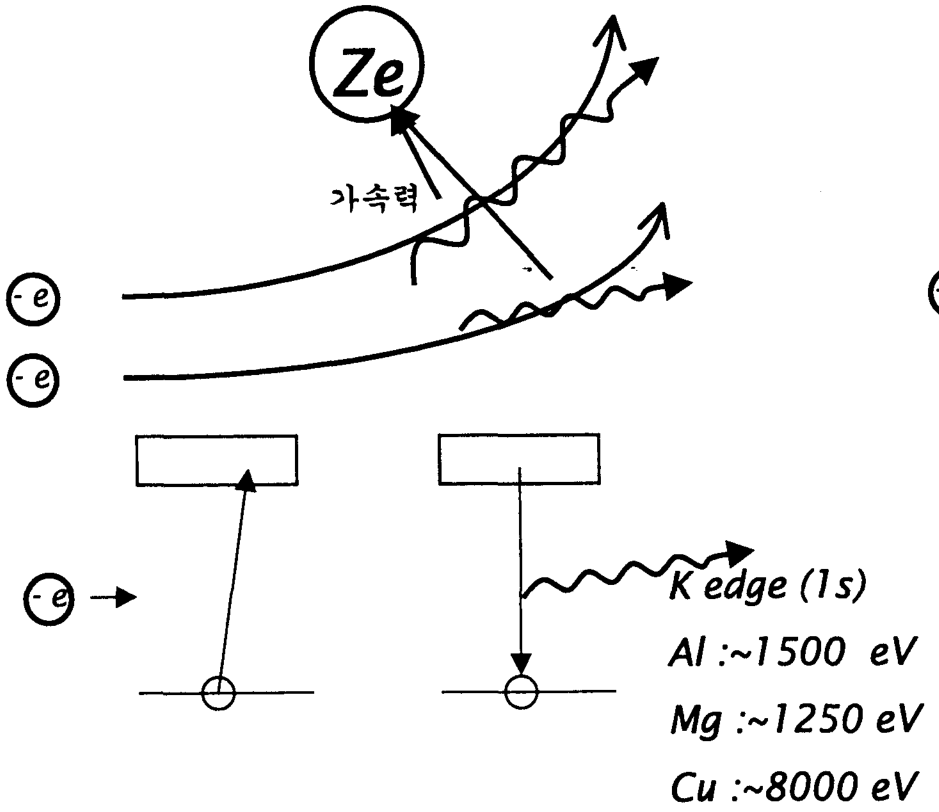
.Critical Energy :2790/5450 eV

.Bending Radius (m) : 6.306

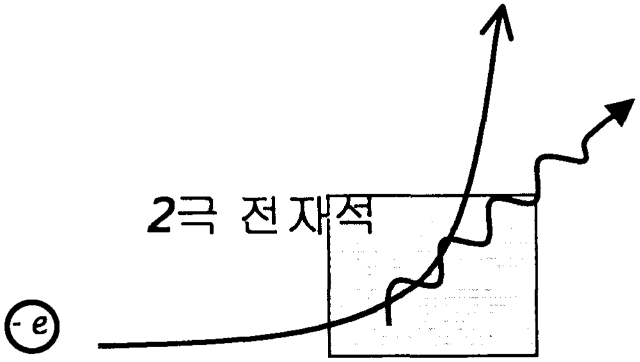
.Dipole Field at 2.0(2.5) GeV(T) : 1.058(1.32)

SR Source vs Conventional Source

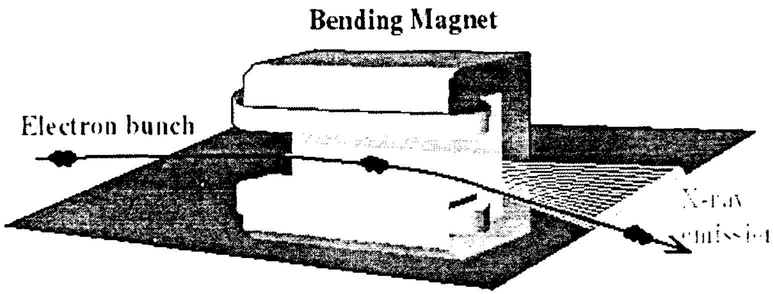
제동 복사 : 고속 전자나 양전자의 궤도가 자장 등으로 휠 때 전자기파가 발생된다.



Conventional X-ray Source



Lorentz force : $F = q/c\ v \times B$



Synchrotron Radiation

Critical Energy
&
Total Bending magnet radiated Power

Power Distribution: $2\int_{\omega_c}^{\infty} P\left(\omega_c\right) d\omega = \int_{0}^{\infty} P\left(\omega_c\right) d\omega$

Critical Energy: $E_c(eV) = \hbar w_c \cong (2.2 \times 10^3) E^3(GeV) / \rho(m) \cong (6.7 \times 10^2) B(T) E^2(GeV)$

Total Power of Bending Magnet: $P \propto E^3 \times B \times i$

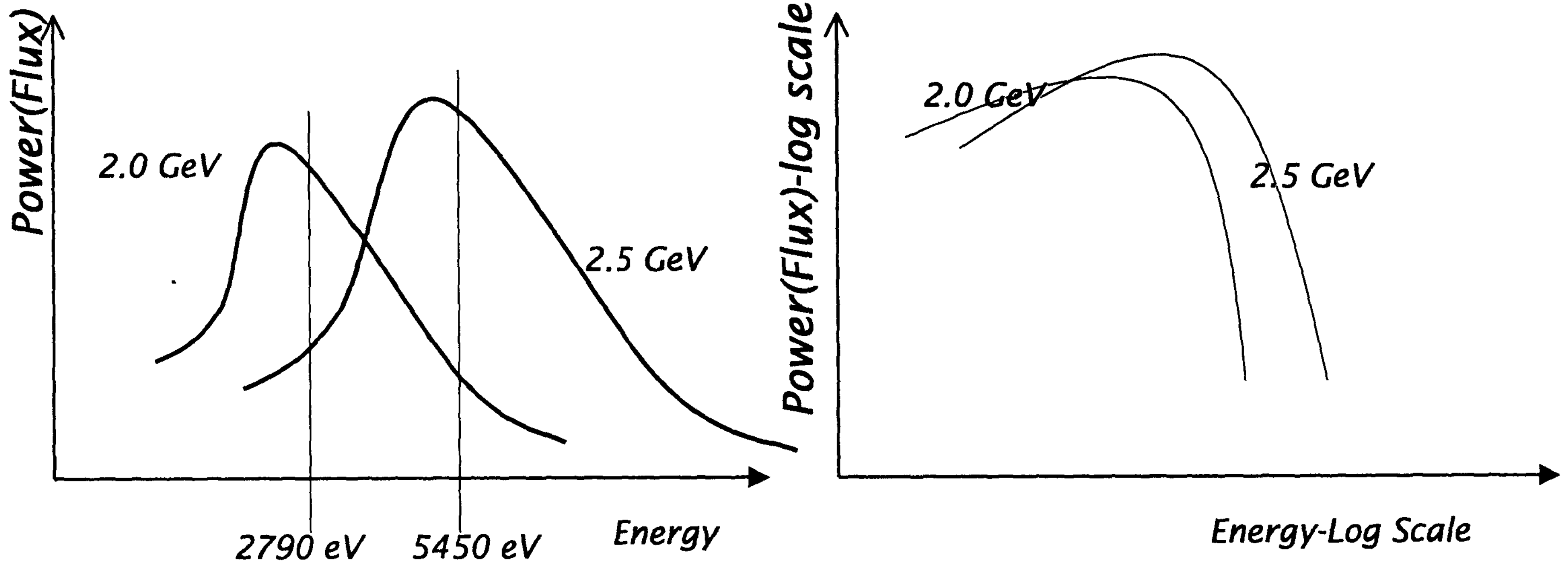
PLS

Critical Energy : $2.2\text{x}10^3\text{x}2^3/6.306$ ~2790 (eV)

: $2.2\text{x}10^3\text{x}2.5^3/6.306$ ~5450 (eV)

$\text{Power}_{2.5\text{ GeV}} / \text{Power}_{2.0\text{ GeV}} = 2.5^3\text{x}1.32 / 2.0^3\text{x}1.058$ ~ 2.4

Power Spectrum

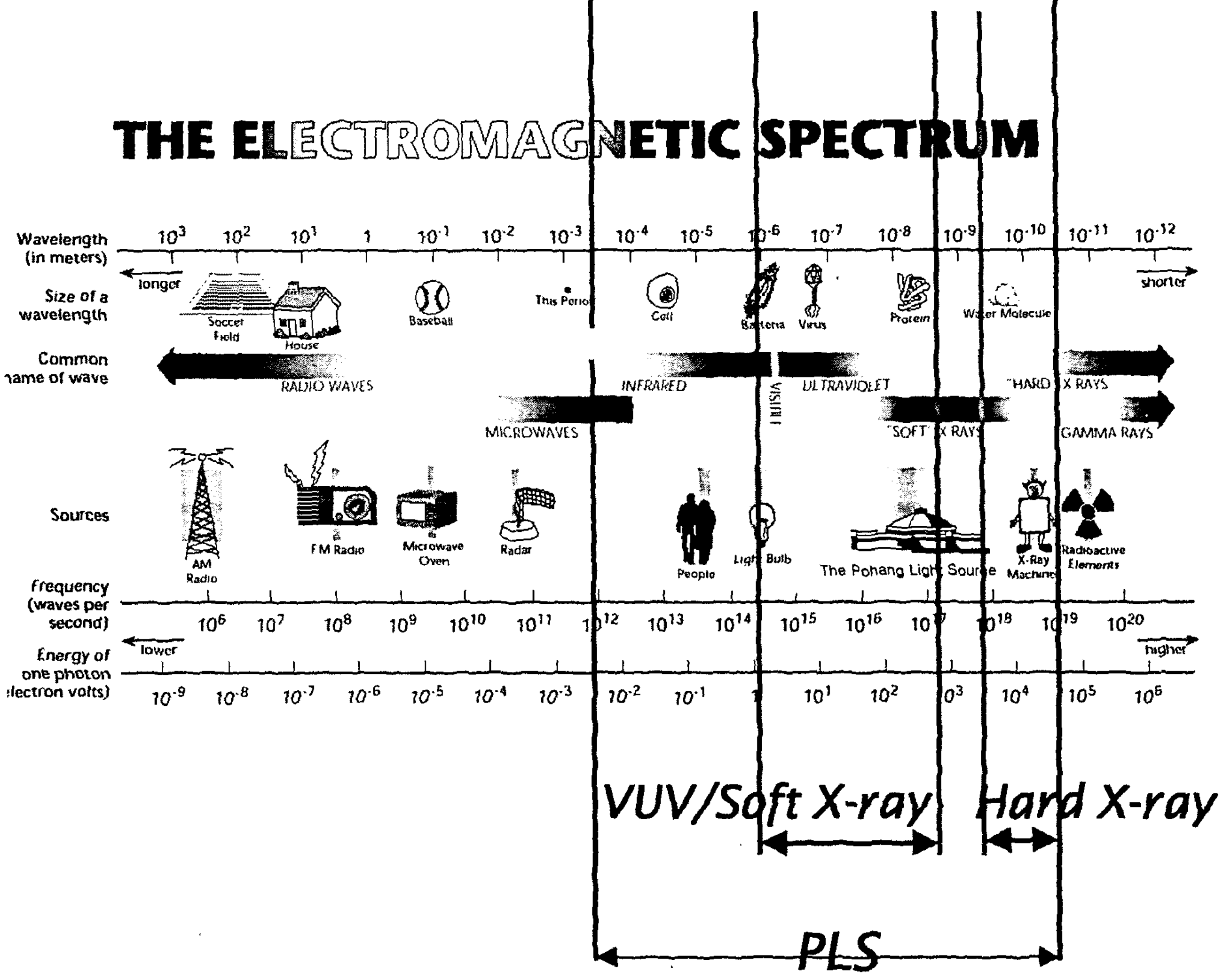


$N(h\nu)=1.256x10^{7}\gamma G_1(\nu)$

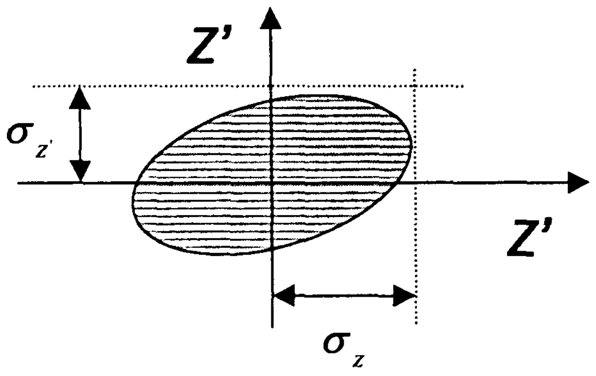
$G_1(\nu) = \nu\int^{\infty} K_{5/3}(\nu)d\nu$

$K_{5/3}$= *a modified Bessel fn of the 2nd kind*

Electromagnetic spectrum



Emittance & Beam size



.Emittance ε_x , ε_z is defined as the area of divergence-size of source : m - rad

. Z'-Z, X'-X area is not changed in the ring

.Beam size is determined directly by the change of the emittance.

$$\varepsilon_x = \varepsilon_x^0 / \left(1 + k_{xz}^2\right)$$

$$\varepsilon_z = k_{xz}^2 \times \varepsilon_x^0 / \left(1 + k_{xz}^2\right)$$

k_{xz}^2 =coupling constant

Coupling Constant : parameter which determines x-z orbit motion, determines the practical emittance

PLS :

ε_x = 12 (18) nm.rad : 2.0 (2.5) GeV

Coupling constant < 10 %

The smaller the coupling constant, the less ε_z

By reducing the coupling constant, reduce the source size

Angular distribution of synchrotron radiation

$$\sigma_R = \frac{565}{\gamma} \times \left(\frac{\varpi_c}{\varpi}\right)^{0.425} (mrad)$$

γ= 1957E (GeV)

~4000 2.0 GeV

~5000 2.5 GeV

At $\omega=\omega_c$, angular width~1/γ rad

~0.25 mrad 2.0 GeV

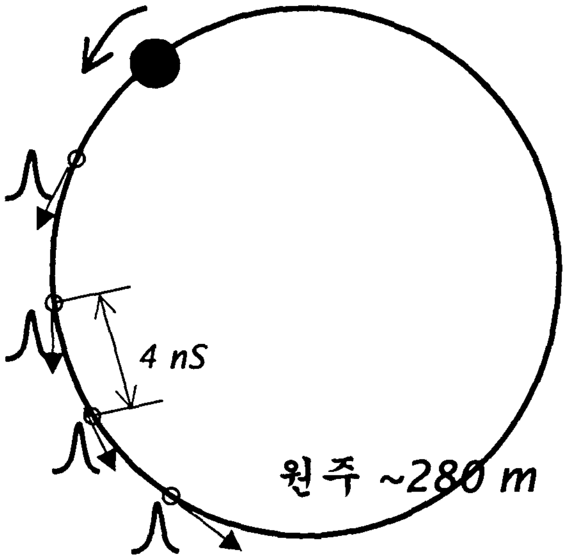
~0.2 mrad 2.5 GeV

Current & Time Structure

Data Sampling Rate ~ Flux ~ Stored Current

PLS ~ 160 mA

If it is continuous current : 2.5 GeV x 0.16 A ~ 0.4 G Watt



1 electron :

$3x10^8$ m/sec /280 m X $1.6x10^{-19}$ C ~ $1.6x10^{-13}$ (C/sec=A)

280 m / $3x10^8$ m/sec ~ 0.96 μS

$160x10^{-3}$ / $1.6x10^{-13}$ ~ 10^{12} electrons in 250 bunch

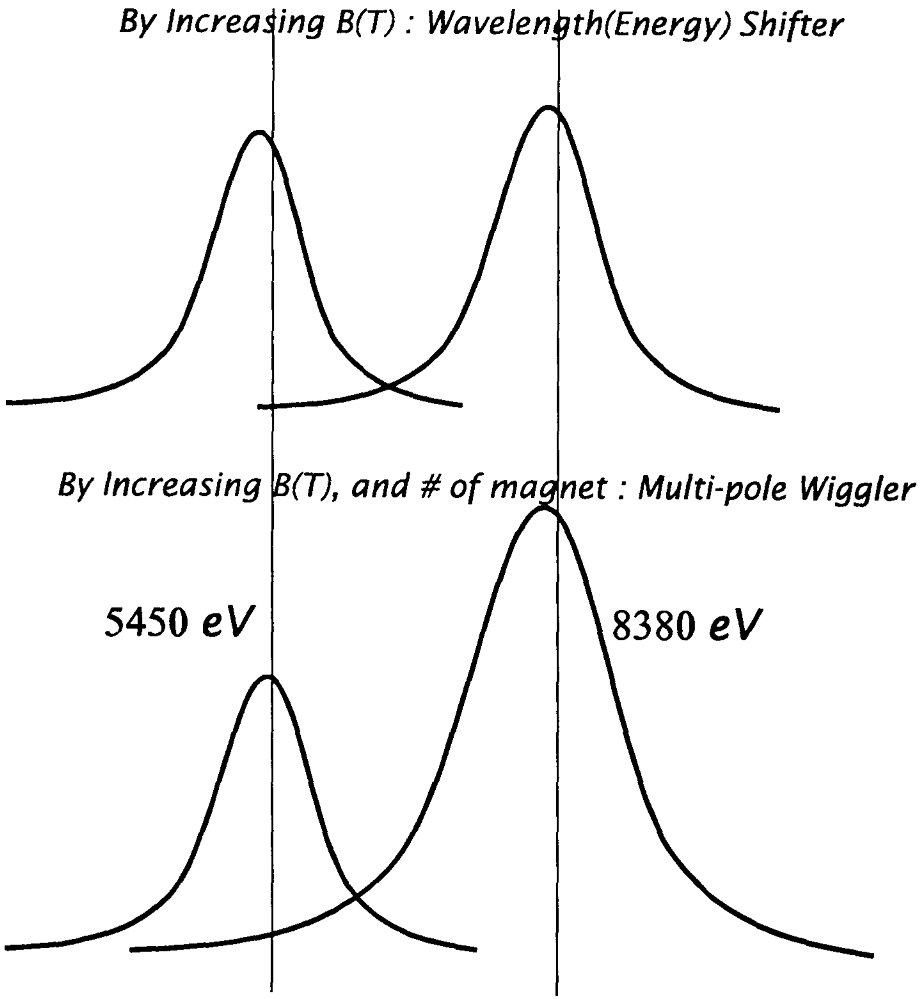
10^{12}/250 ~ $4x10^9$ electrons/bunch

0.96 μS/250 ~ 4 nS pulse

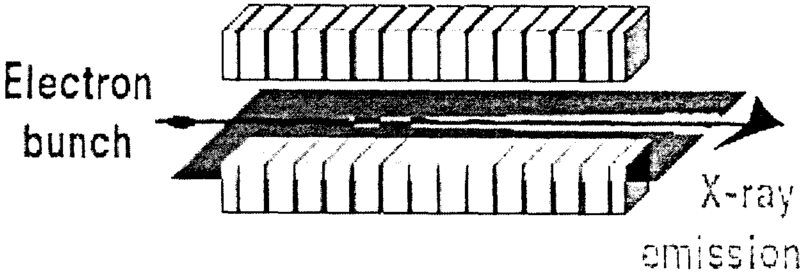
Time structure from ~ 1μS to 4 nS by changing # of bunch

Insertion Device (Wiggler)

Critical Energy $\propto B(T)E^2(GeV)$ Power $\propto B(T)E^3(GeV)$


By Increasing B(T) : Wavelength(Energy) Shifter

By Increasing B(T), and # of magnet : Multi-pole Wiggler



PLS :

Bending : 1.3 T

Multi-pole wiggler : 2T, 14 period

$E_C = 5450\ eV*2/1.3 \sim 8380\ eV$

$P_{14\ pole\ wiggler} / P_{bending} \sim 2/1.3*14 \sim 20$ times

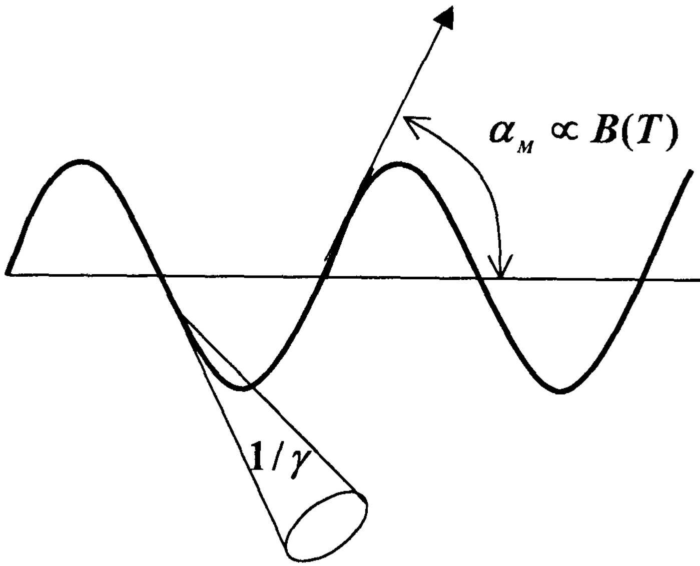
Insertion Device (Undulator)

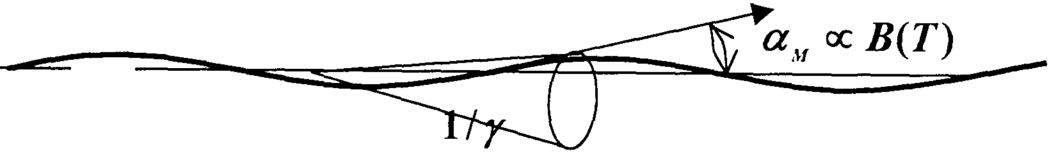
With strong magnetic field, $\alpha_M >> 1/$ *: Wiggler*

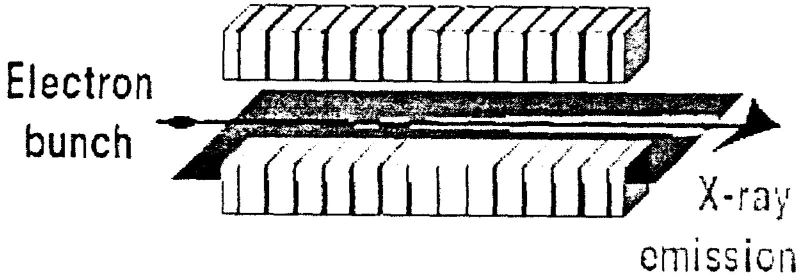
With weak magnetic field, $\alpha_M < 1/\gamma$

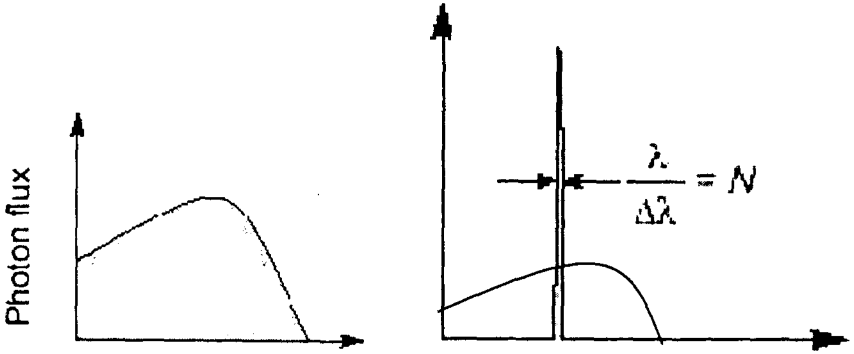
: Interference of a specific wavelength

: Undulator

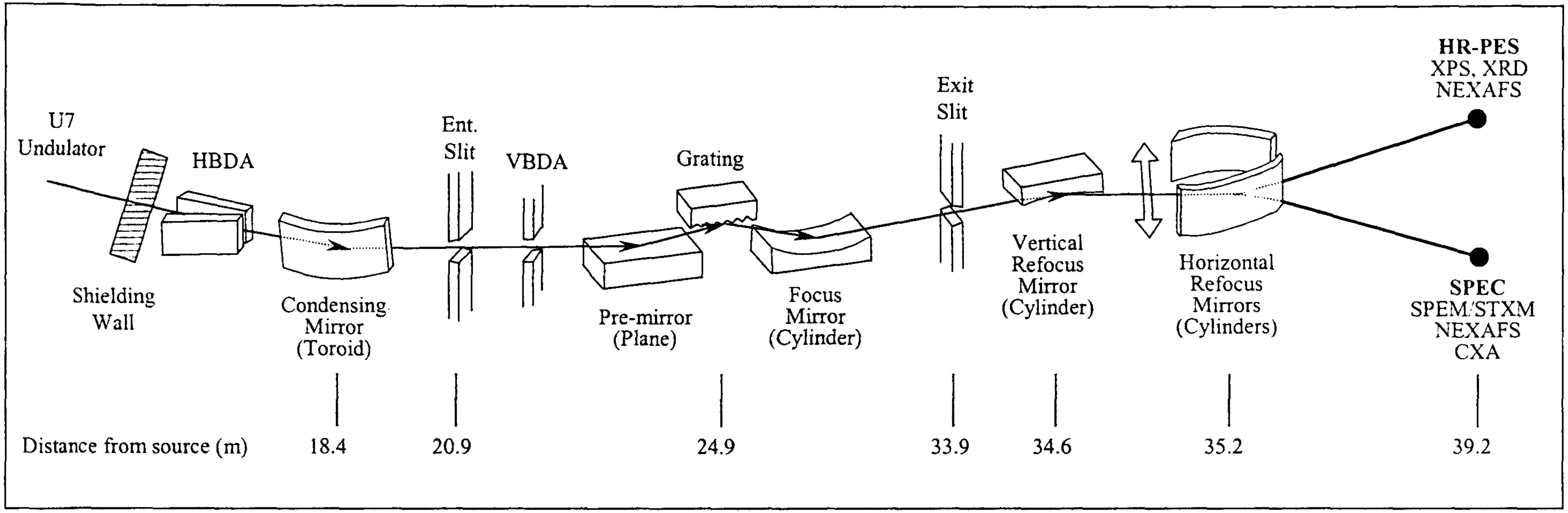








Beamlines (방사광관)



.Beamline delivers the necessary photon beam to the experimental station

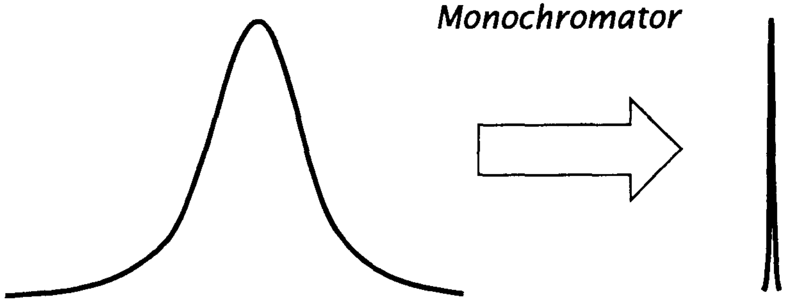
.Mirror system : guide & focus the photon beam.

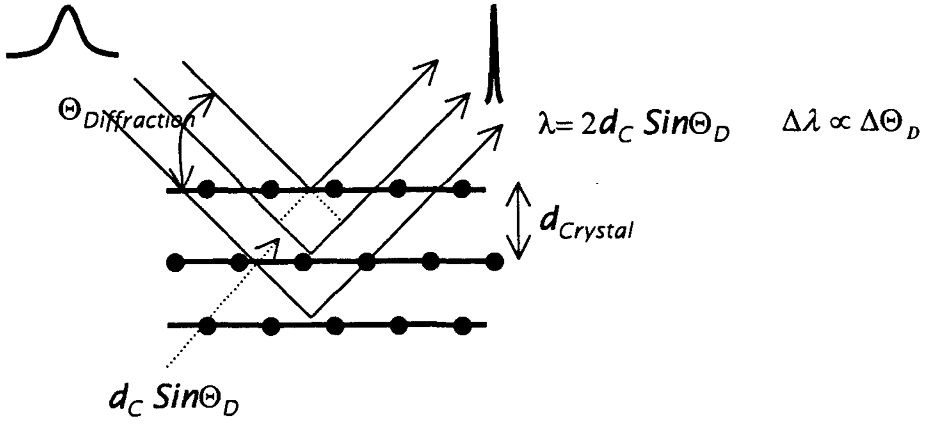
0.2 mrad x 30 m = 6 mm, 2 mrad x 30 m = 6 cm without re-focusing

.monochromators : select the right photon energy for the experiment

Double Crystal Monochromator, PGM, SGM,...

How to make a monochromatic photon





- o Energy Resolution
- o Angle Resolution
- o Photon Flux
- o Energy tuning stability
- o Repeatability
- o
- o

$d_{Crystal}$ of Si(111) ~ 0.3135 nm

$\Theta_D \sim 5^0 - 30^0$

$E_{Scan\ Range}$: 0.055 – 0.31 nm = 4 - 22.5 keV

$d_{Crystal}$ of Si(311) ~ 0.124 nm for higher energy

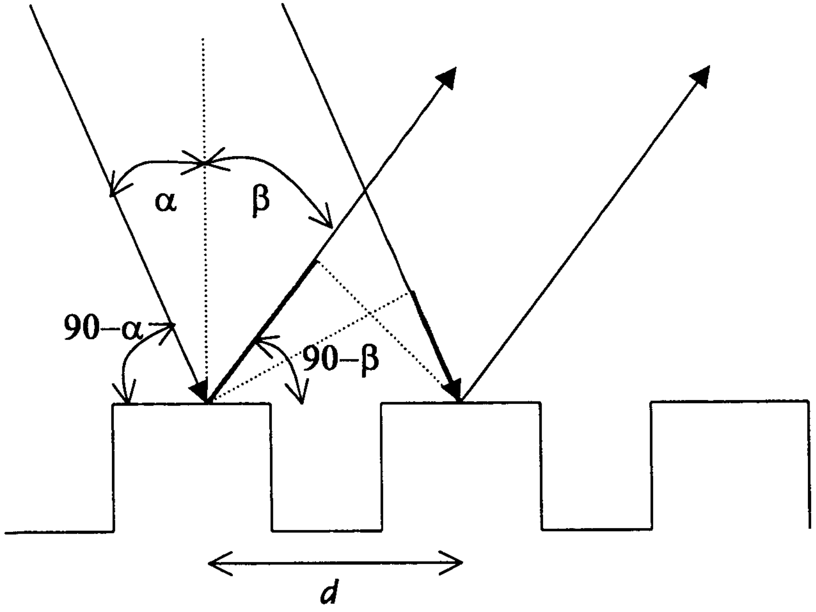
$d_{Crystal}$ of Ge(111) ~ 0.327nm for lower energy

Soft X-ray/VUV

For soft X-ray/VUV : 10 – 2,000 eV = 0.62 –12 nm

$\Theta_D \sim 1^0 \rightarrow d_{Crystal} \sim 17$ nm $\Theta_D \sim 30^0 \rightarrow d_{Crystal} \sim 0.62$ nm

Not Available in Nature



경로차= —— - ——

$= d\cos(90-\beta) -□\, d\cos(90-\alpha)$

$= d\sin(\beta) - d\sin(\alpha)$

$\alpha=87, \beta=87 \longrightarrow 7.6 \times 10^{-4}\, d$

For monochromating 2000 eV,
$d = 0.62/7.6 \times 10^{-4} = 815$ nm ~ 1200 lines/mm

Soft X-ray vs Hard X-ray

Soft X-ray	*Hard X-ray*
10 – 2,000 eV	*2,000 eV-*
Gratings	*Si, Ge Crystals*
성분 분석	구조 분석

성분분석 : *dE < 0.25 eV* 이하 필요

E/dE ~ 2,500/0.25 ~ 10,000 이상 필요

*Hard X-ray*를 성분분석에 사용하기 위해서는 고성능 고에너지용 *Analyzer* 및 고 분해능 *monochromator* 개발 필요

.구조 분석을 위한 파장 $\lambda < 0.2 - 0.4$ *nm = 3 – 12 keV*

광전자 분광학	*XRD, EXAFS*
NT	*BT*

NT+BT converged

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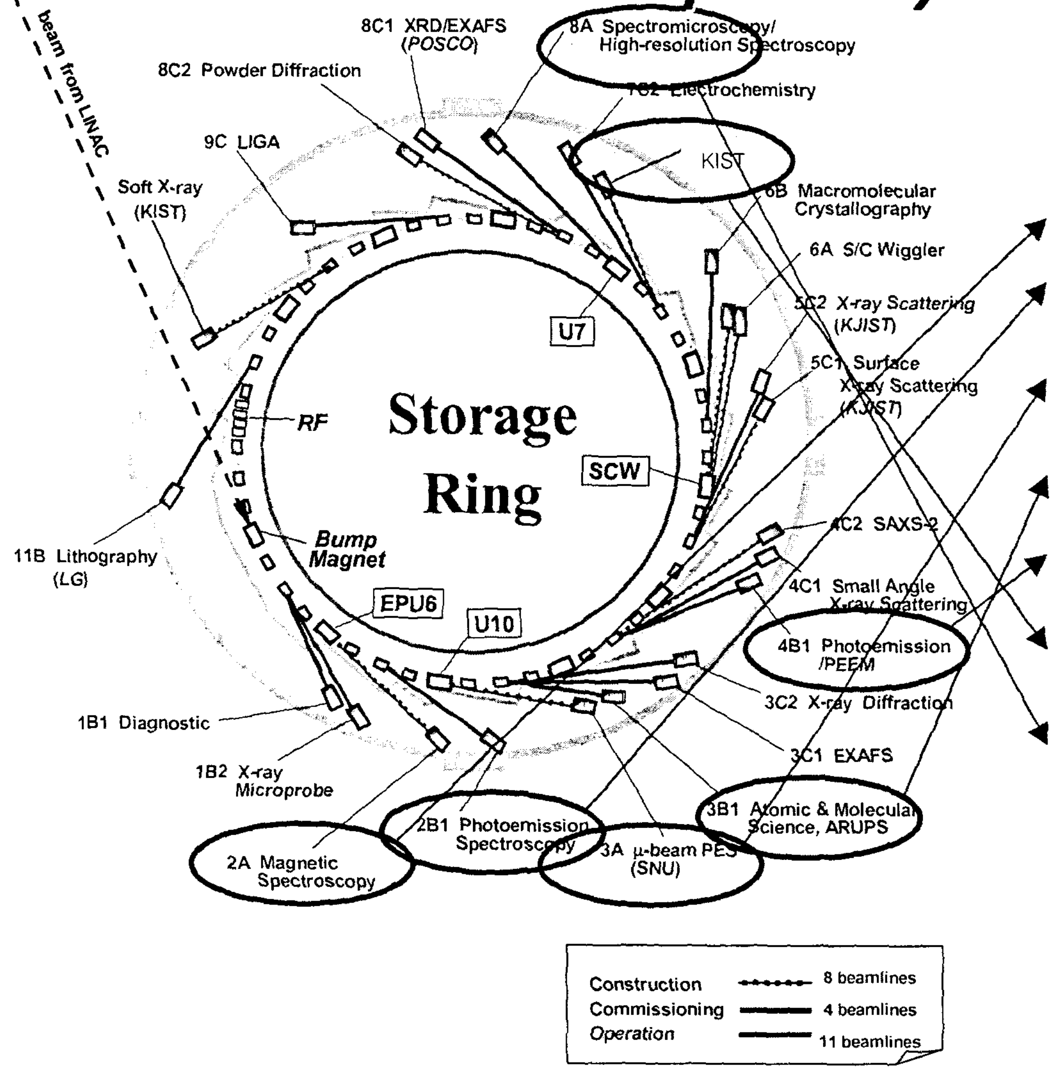
Why Synchrotron Radiation as Soft/VUV research tools

- ***high brilliance :*** **고분해*, low concentration sample,***
- *high collimation : small sample*
- ***energy tunability : sensitivity selection***
- *polarization :*자기 성질 실험
- *Coherenece : just begin to explore*

PLS soft X-ray Programs



2A1 Magnetic Spectroscopy

2B1 Photoemission Spectroscopy

3A1 μBeam Spectroscopy

3B1 Atomic & Molecular Science

4B1 Photoemission Electron Microscopy

7B1 Soft X-ray Spectroscopy & Reflectivity

8A1 Spectro Microscopy & HR Spectroscopy

PLS soft X-ray Programs

.Spectroscopy : Element Analysis

.Photoemission Spectrosopy

.X-ray Absorption Spectroscopy/NEXAFS

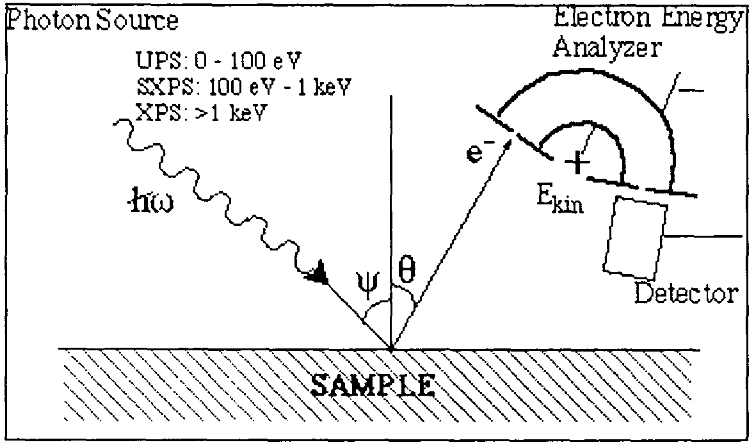
.Microscopy : Image + Element Analysis

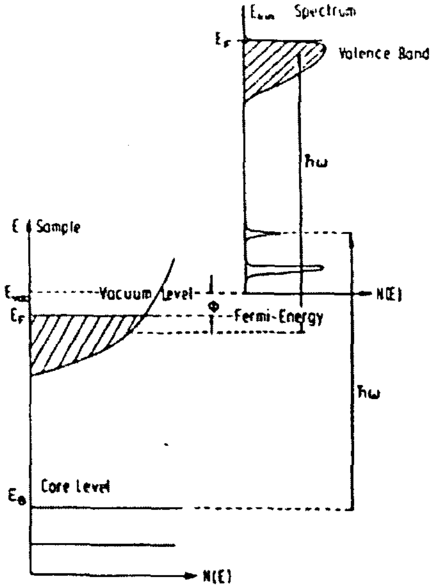
.PhotoEmission Electron Microscopy(PEEM)

.Scanning PhotoEmission Microscopy

Photoemission Spectroscopy

Beamlines : 2A1, 2B1, 3A1, 3B1, 4B1, 7B1, 8A1

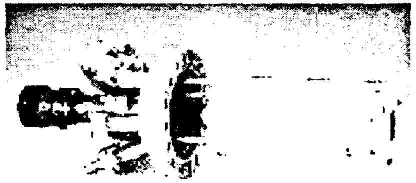




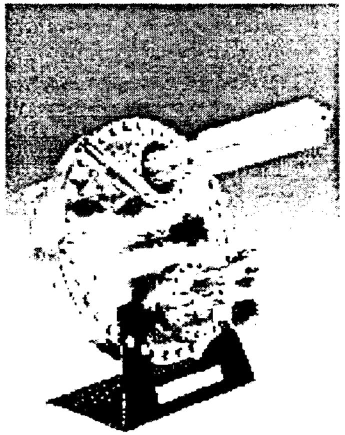
Electron Analysers

.Cylindrical Mirror Analyser

100 - 150 mm outer diameter, E/dE ~ 200 without pre-retarding lens, working distance ~ 5mm :good for high efficiency, low resolution : Auger Spectroscopy



.Hemispherical Analyser



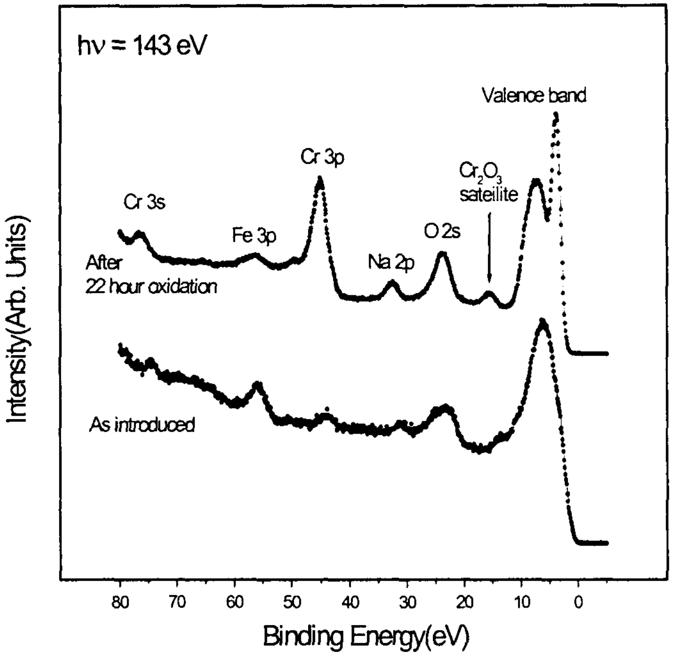
100 -200 mm outer diameter, E/dE~1,000 - 2,000 working distance 20 -50 mm : good for low-efficiency, high resolution :

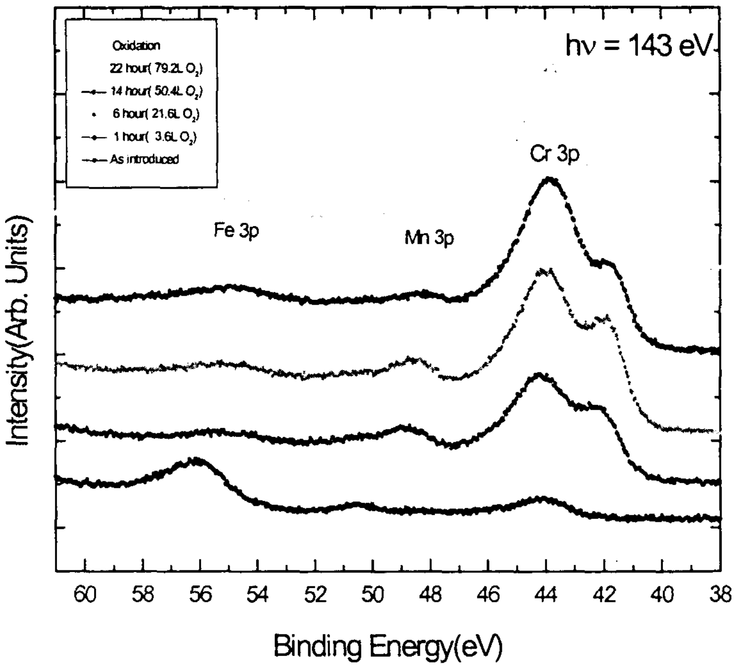
Photoemission spectroscopy

$dE/E \sim \omega/2R_o$

Fixed Pass Energy : constant energy resolution

The change of the surface constituents before and after oxidation





- 450°C, 1x10^{-9} Torr O_2 treatments.
- Fe_2O_3 was a main constituents on the as introduced sample surface and Cr_2O_3 after oxidation.

Pretreatment effects by aqua-regia solution on field emission of diamond film

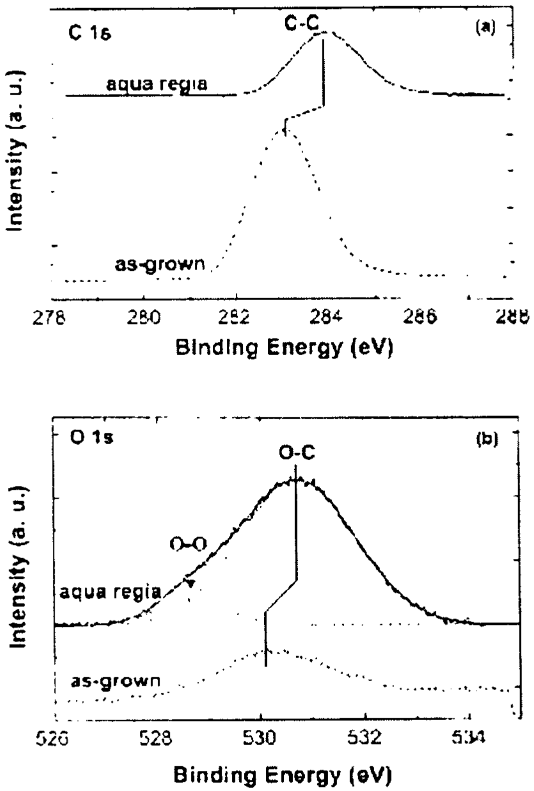


FIG. 2. (a) C 1s peak and (b) O 1s peak for both as-grown and aqua-regia-treated diamond films, measured by SRPES.

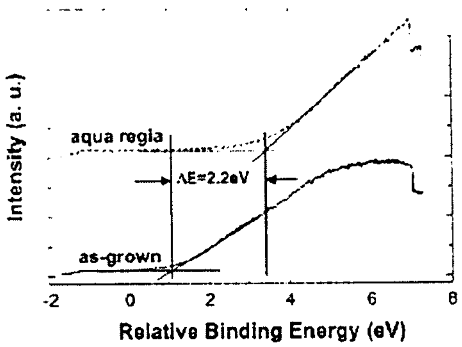


FIG. 3. Valence-band spectra, measured by SRPES, for the as-grown and aqua-regia-treated diamond films.

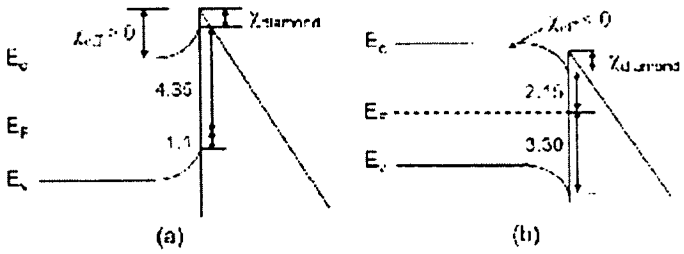
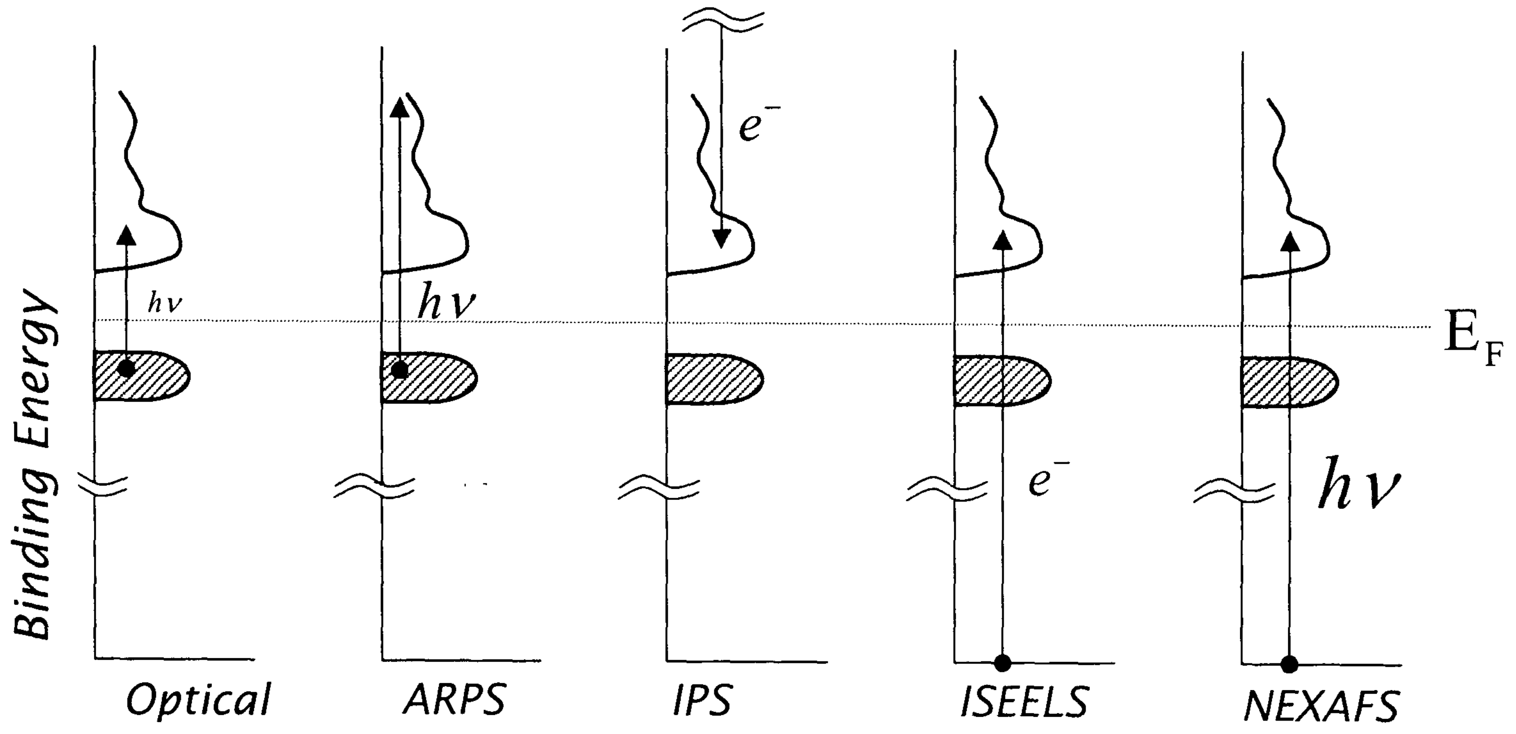


FIG. 4. Schematic energy-band diagrams deduced from Fig. 3; (a) before aqua-regia treatment and (b) after aqua-regia treatment.

Schematics of Spectroscopies for Unoccupied Density of States

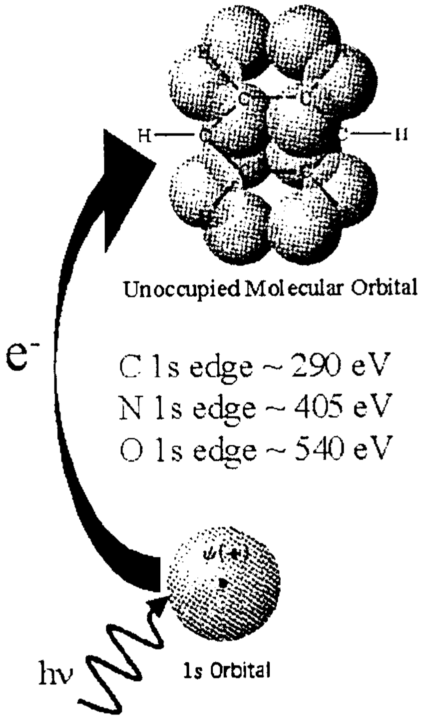


NEXAFS(near-edge X-ray absorption fine structure)

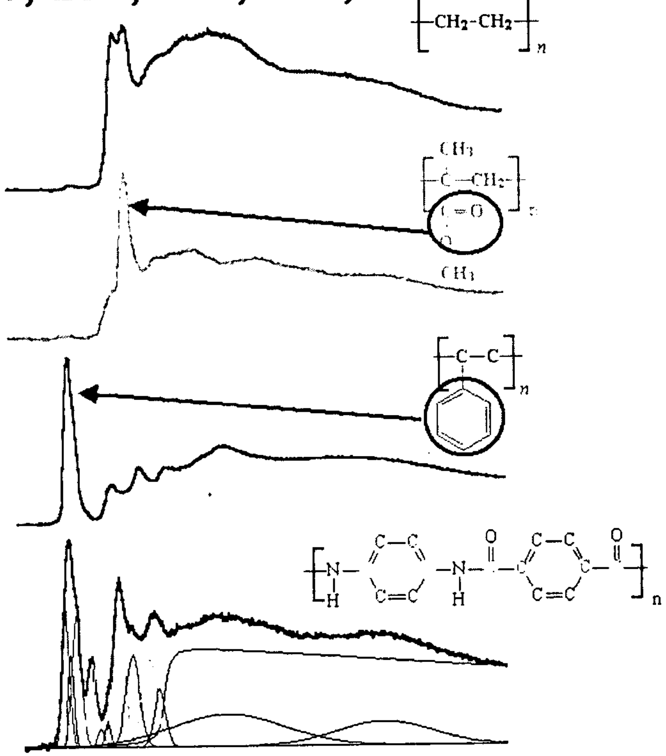
$$\tilde{\sigma}(E) = \frac{4\pi\hbar^2}{m^2}\frac{e^2}{\hbar c}\frac{\rho_b(E_f)}{E}\left|\langle\psi_f|\mathbf{e}\cdot\mathbf{p}|\psi_i\rangle\right|^2$$

Near Edge X-ray Absorption Fine Structure (NEXAFS) Spectroscopy

Beamlines : 2A1, 2B1, 4B1, 7B1, 8A1



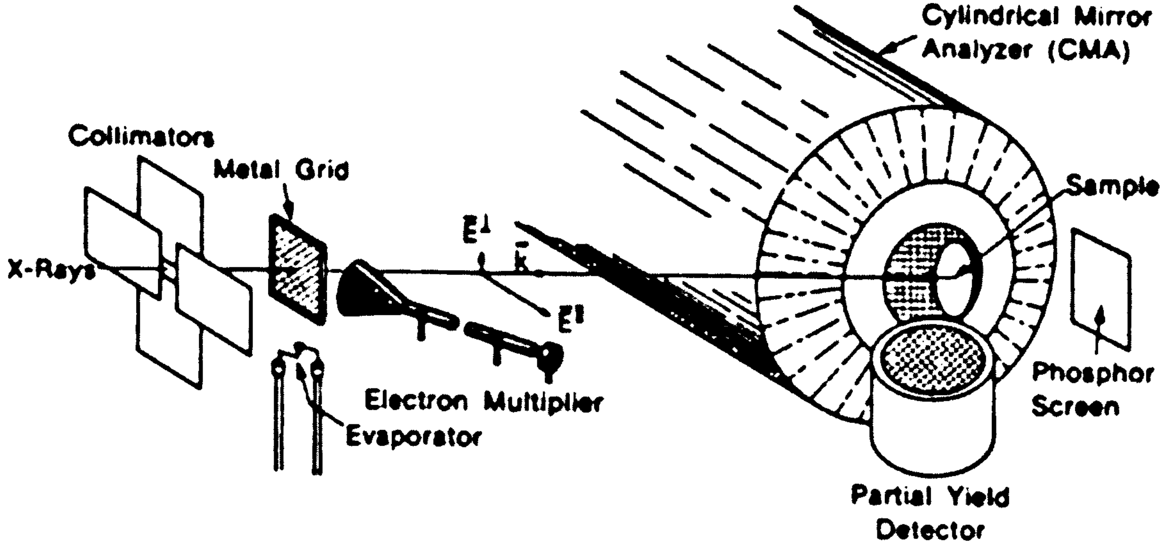
C 1s edge ~ 290 eV
N 1s edge ~ 405 eV
O 1s edge ~ 540 eV



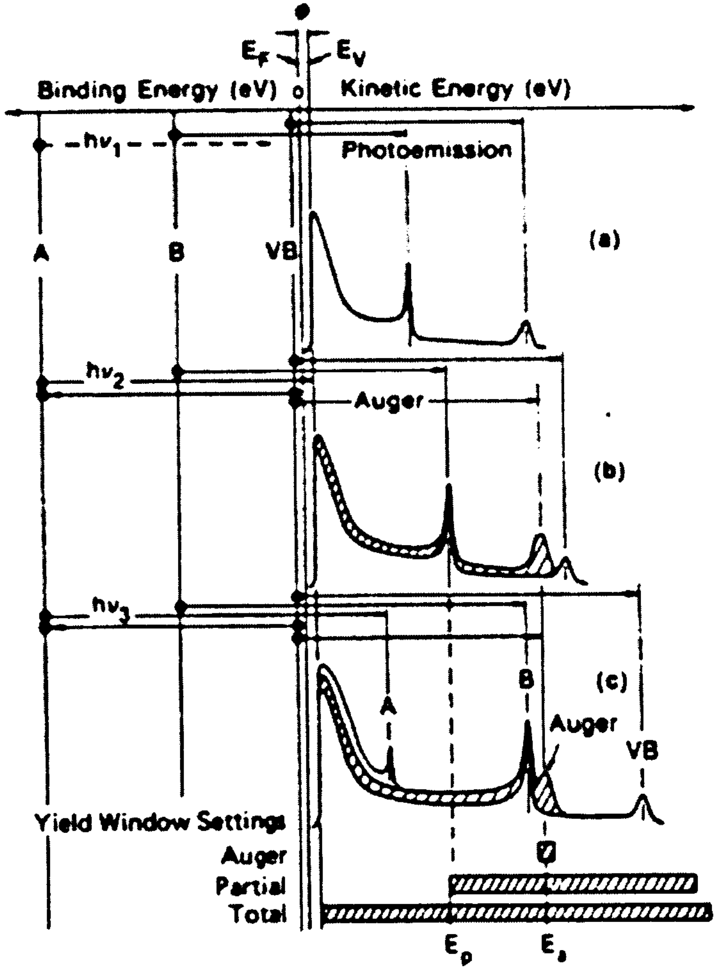
Tunable photons from a synchrotron radiation beamline can be used to interrogate the likelyhood of absorption in a compounds as a function of photon energy.
The spectrum thus obtained is reflecting the chemical composition and the bonding environment of the compound. Quantitative compositional analysis of a materials can be performed with a few per cent accuracy

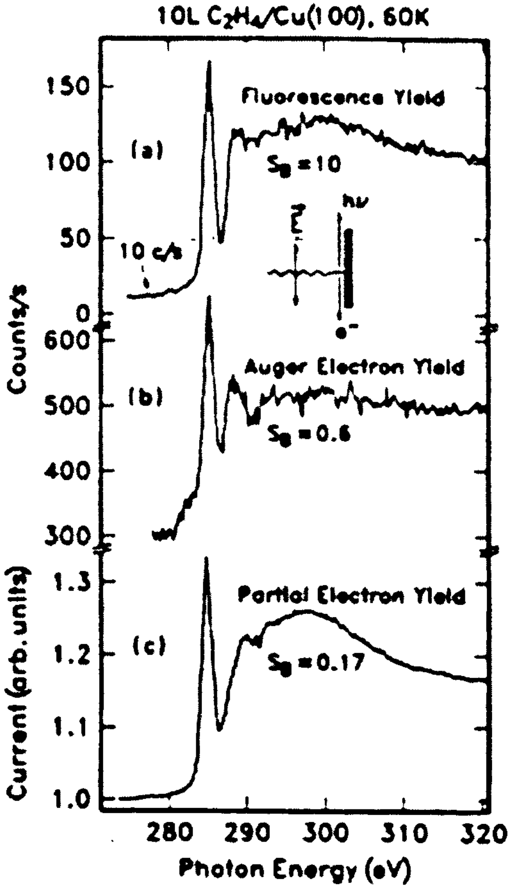
if spectra of relevant model compounds are utilized.

NEXAFS실험 장치 및 *detectors*



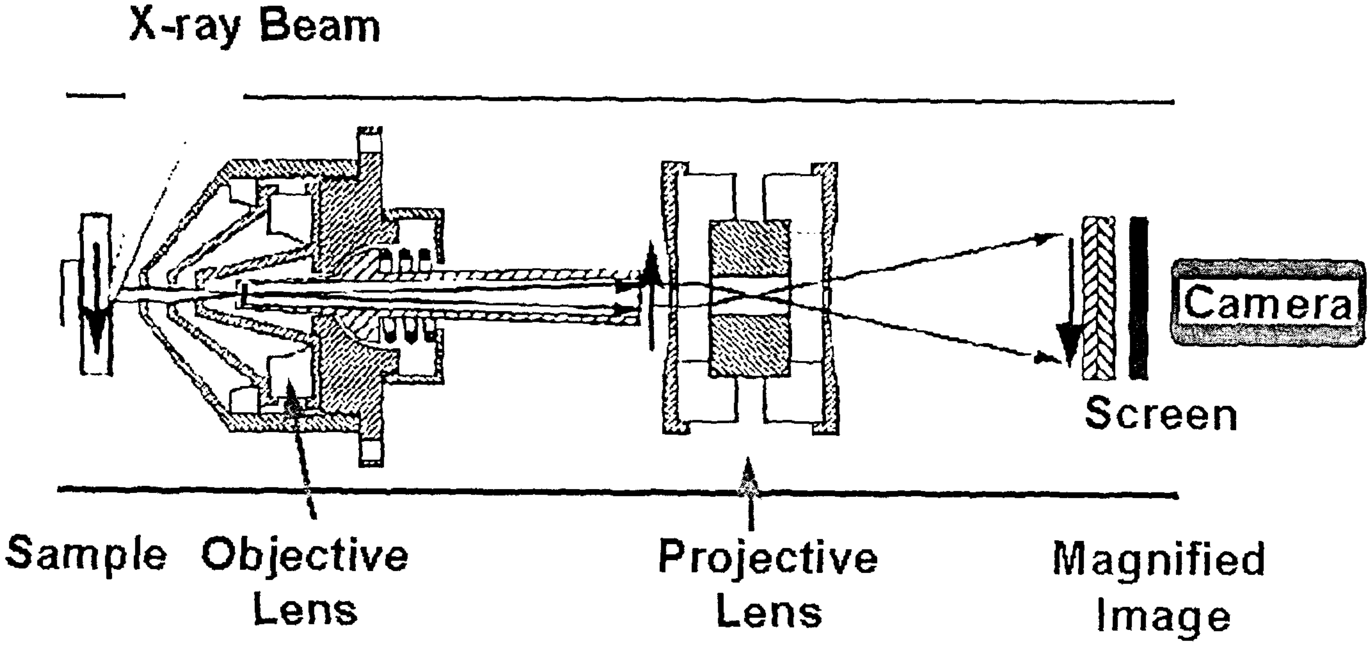
NEXAFS Spectrums



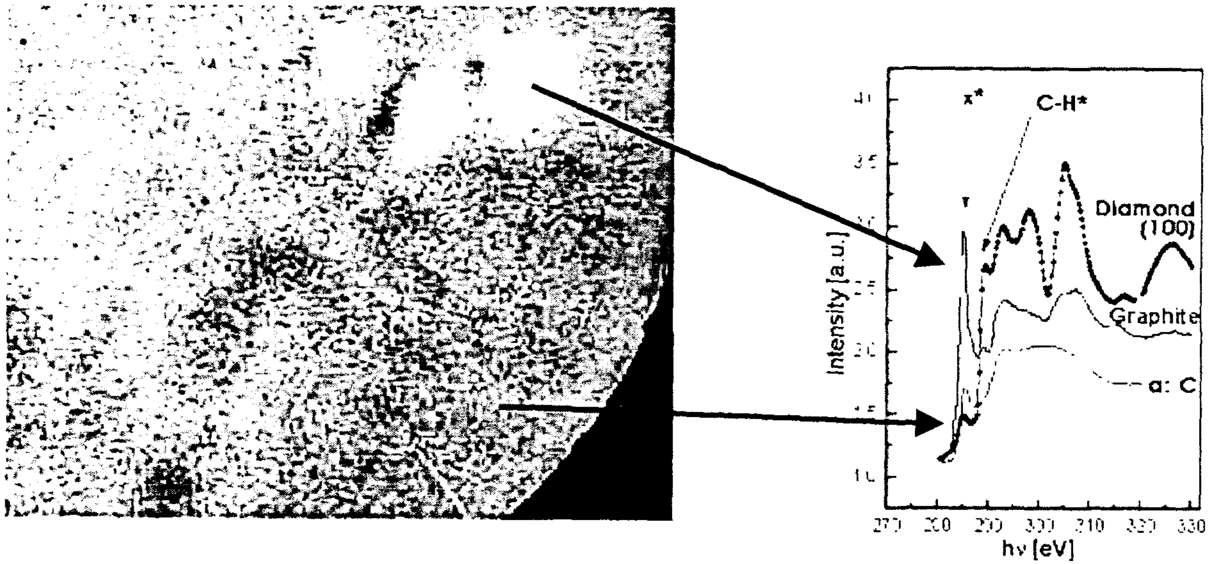


X-ray PhotoEmission Electron Microscopy
(X-PEEM)

Beamlines : 2A1, 4B1

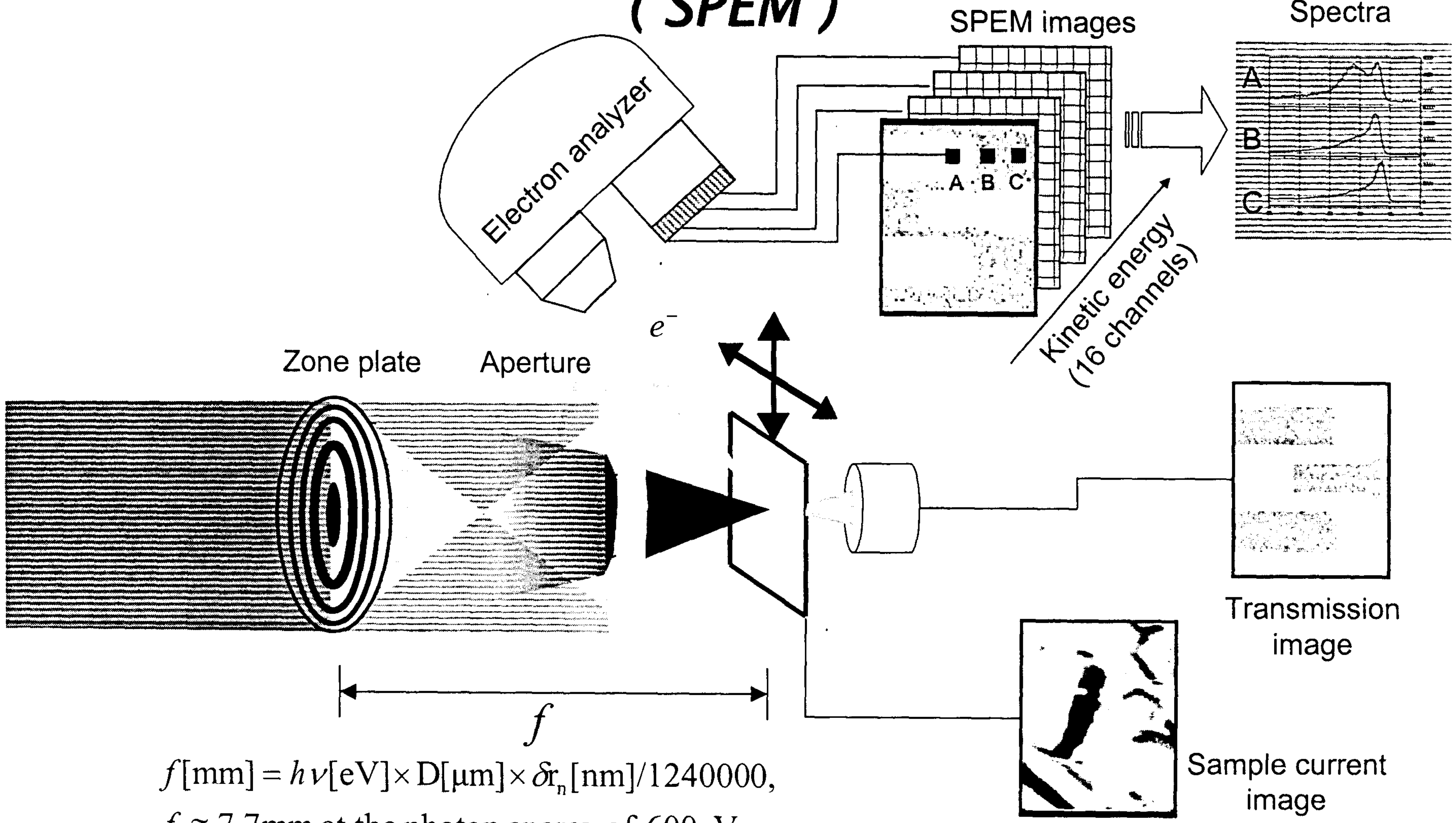


Diamond film studied by X-PEEM



Orbital mapping of carbon-pi*
Element specific imaging (spectromicroscopy) and microspectroscopy of a (100) diamond film reveal the presence of graphite (bright spots). (40 x 50 μm^2).

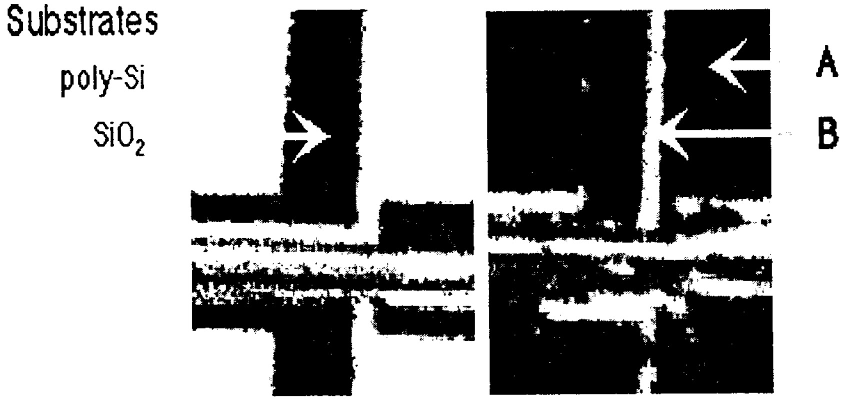
Scanning PhotoEmission Microscopy (SPEM)

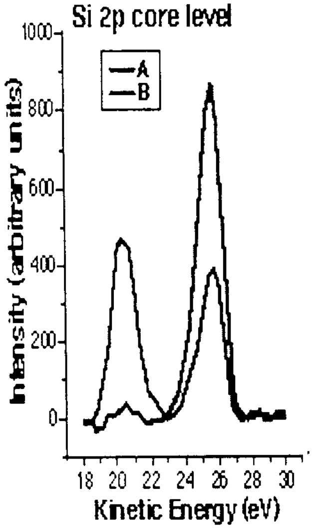


f[mm] = $h\nu$[eV] × D[μm] × δr_n[nm]/1240000,

$f \cong 7.7$mm at the photon energy of 600eV.

$TiSi_2$ studied by SPEM

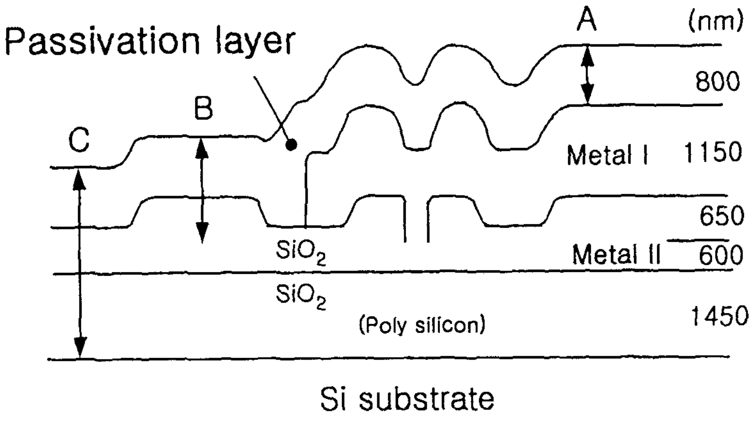




The spectrum of photoemission of a Si(111) surface with a lineform analysis. Each component S_1 to S_4 corresponds to one type of atomic position.

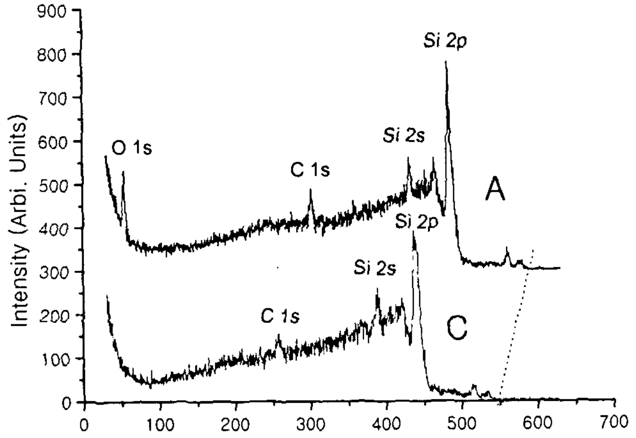
SPEM study of sensor chip: depth probe on microstructures embedded in an insulating layer(I)

Cross section of a sensor chip

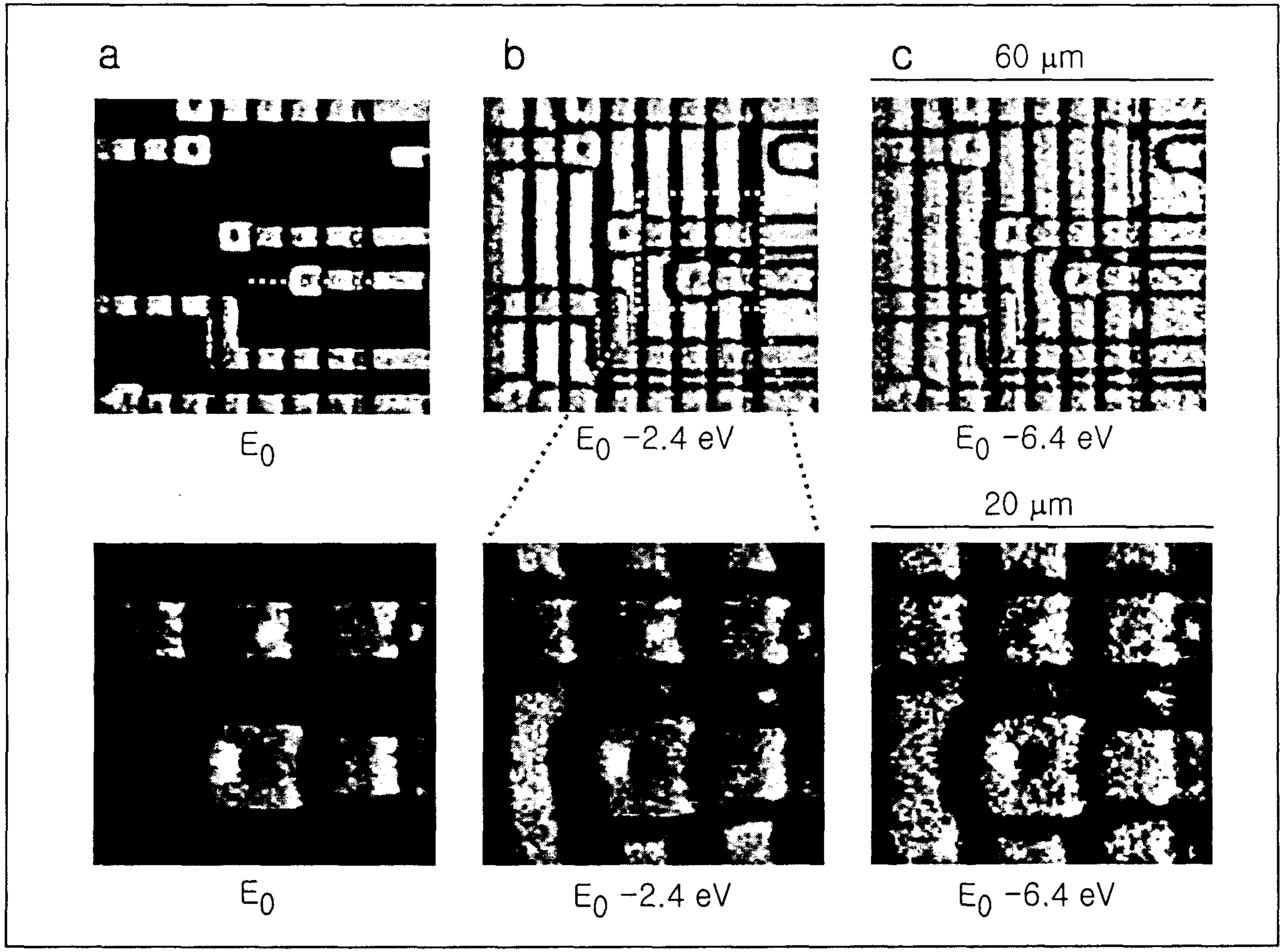


Spectra obtained at A and C points

Spectrum obtained above the silicon substrate shows further spectral line shift compared to that obtained above metal I layer.



SPEM images obtained at photoelectron kinetic energies at E_0(a), E_0-2.4eV(b), and E_0-6.4eV(c). Image (a) shows metal I layer, and (b) shows metal II and metal I layers Image (c) shows metal I, II layers and silicon substrate.



Synchrotron & Nano Technology

Nano Technology ?

1 - 100 nm size에서 일어나는 현상 및 구조물을 이용하는 기술

Need : 1 -100 nm 공간 분해능을 가진 ***spectroscopy*** 실험 기술

Present :

μ-XPS, μ-XRD, PEEM, SPEM

Future :

10 nm 공간 분해능 ***PEEM, 25 nm*** 공간 분해능 ***SPEM, 20 nm SPELEEM***

High Flux EXAFS, High Flux XRD, High Resolution Spectroscopy

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