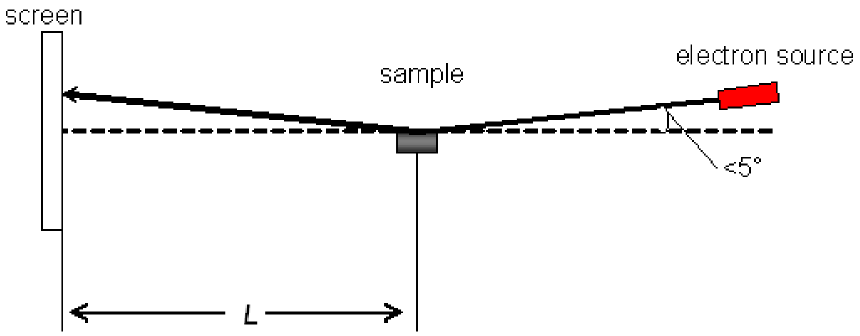
# X I　Reflection high energy electron diffraction

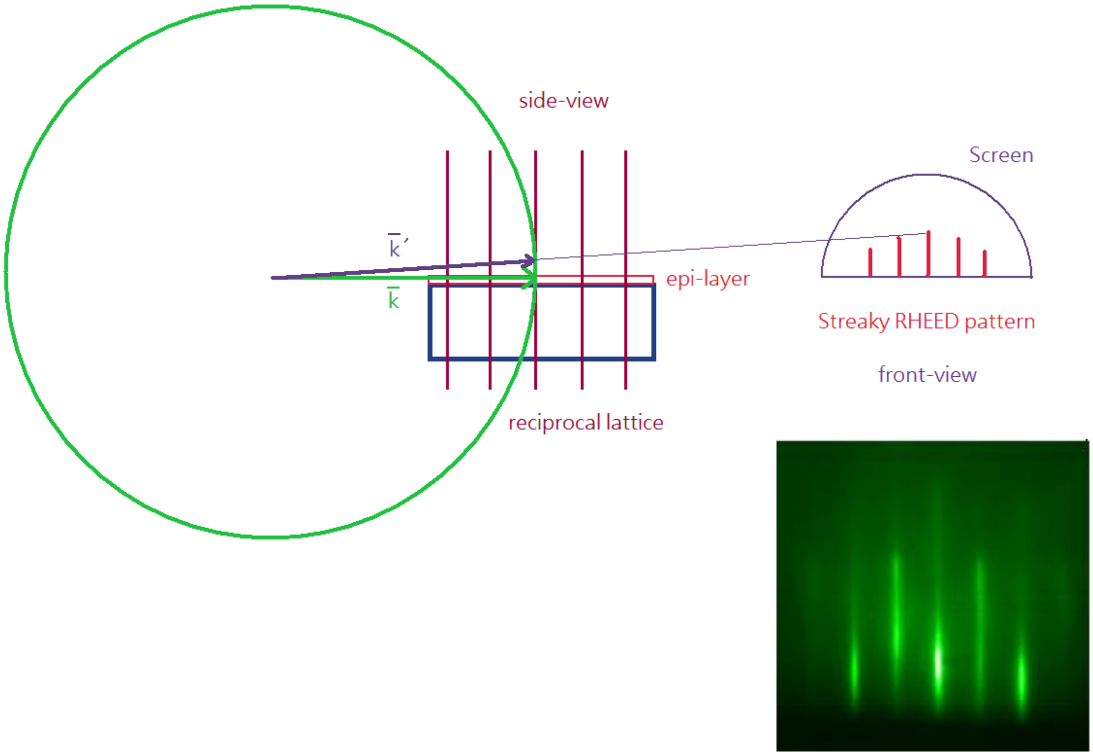
- Surface reconstruction studied by RHEED

  --- used in MBE (molecular beam epitaxy)



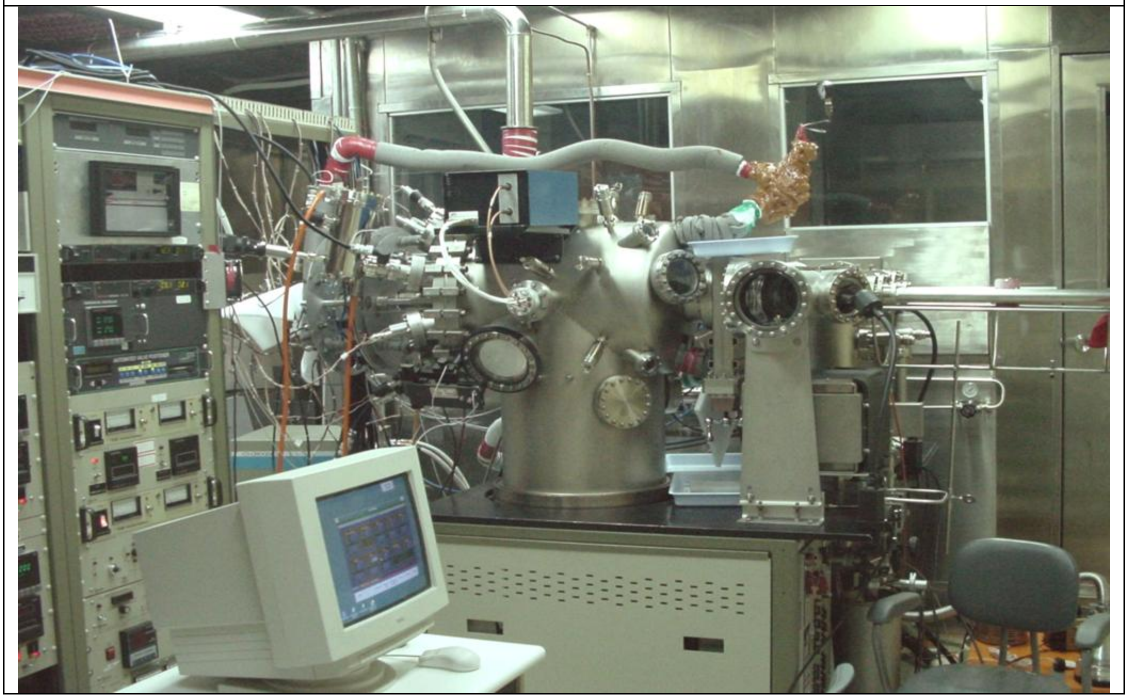
Schematic of a RHEED setup.

The distance from sample to screen, L, and the energy of the electron beam must be known to derive the lattice spacings of the crystal.

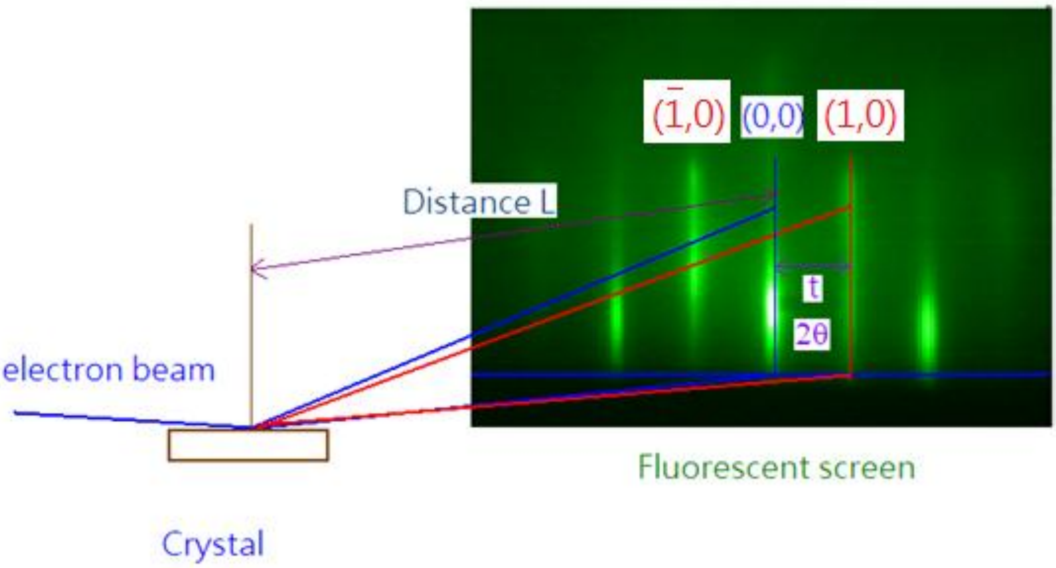


Streaky RHEED pattern

Varian Modular Gen-II MBE system
in the lab. of Prof. Huang 黃金花, MSE, NTHU



(1) Streaky pattern



$$t = L \cdot \tan(2\theta)$$
$$2d_{hk}\sin\theta = \lambda$$

$$\lambda = 2\frac{a}{\sqrt{h^2+k^2}}\sin\theta$$

Since $\lambda \ll a$ when $\theta$ is small

$$t = L\cdot\tan(2\theta) = L\sin(2\theta) = L2\theta$$

$$\lambda = 2\frac{a}{\sqrt{h^2+k^2}}\frac{t}{2L}$$

$$a = \frac{\sqrt{h^2+k^2}\lambda L}{t}$$

Higher accuracy at longer L since t is longer.

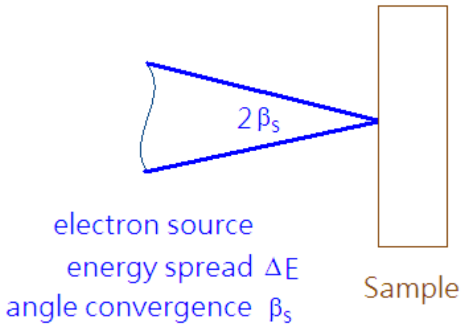
## (2) Coherence zone

The electron beam can be treated an in-phase source only within a coherence zone.

The finite coherence zone is due to both finite convergence and finite energy spread of the electron beam.

### (2-1) Coherence zone of LEED

-Suppose that E=50-200 eV, $\Delta E = 0.5\ \mathrm{eV}$, and $\beta_s = 10^{-2}\mathrm{rad}$ for electron gun in LEED,



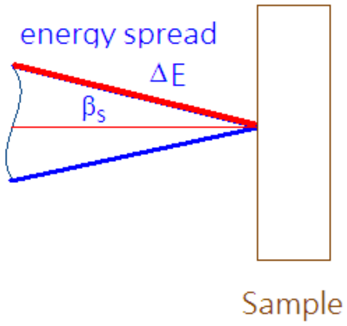
(a) Energy spread $\Delta E$ of incident electrons gives time incoherent

$$E = \frac{\hbar^2 k^2}{2m}$$

$$\Delta E = \frac{\hbar^2}{2m}2k\Delta k$$

Therefore,

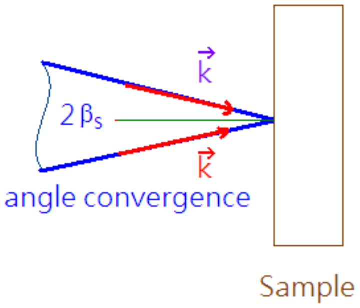
$$\Delta k = \frac{k\Delta E}{2E}$$



Resolved parallel to surface, for small $\beta_s$

$$\Delta k_{\parallel}^{t} = \frac{k\Delta E}{2E}\sin\beta_s \cong \frac{k\Delta E}{2E}\beta_s$$

(b) Spread in arrival angle over $2\beta_s$ gives spatial incoherence,



$$\Delta k_{\parallel}^{s} = k\sin\beta_s - (-k\sin\beta_s) \cong k \cdot 2\beta_s$$

(c) Combine uncertainties and define coherence zone diameter $\Delta X$

$$\Delta X \Delta k_{\parallel} = 2\pi$$

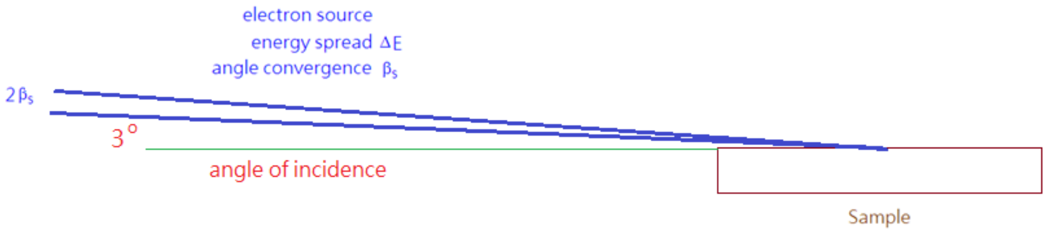
$$\Delta k_{\parallel} = \sqrt{\Delta k_{\parallel}^{t\,2} + \Delta k_{\parallel}^{s\,2}}$$

$$\Delta X \cong \frac{\lambda}{2\beta_s\sqrt{1 + \left(\frac{\Delta E}{4E}\right)^2}}$$

$$\Delta X \cong 50 - 100\ \text{Å}$$

## (2-2) Coherence zone of RHEED

Suppose that $E = 25\ \mathrm{keV}$, $\Delta E = 2\ \mathrm{V}$, and $\beta_s = 10^{-5}\mathrm{rad}$ for electron gun in RHEED,



(d) Energy spread $\Delta E$ of incident electrons gives time incoherent

$$E = \frac{\hbar^2 k^2}{2m}$$

$$\Delta E = \frac{\hbar^2}{2m} 2k\Delta k$$

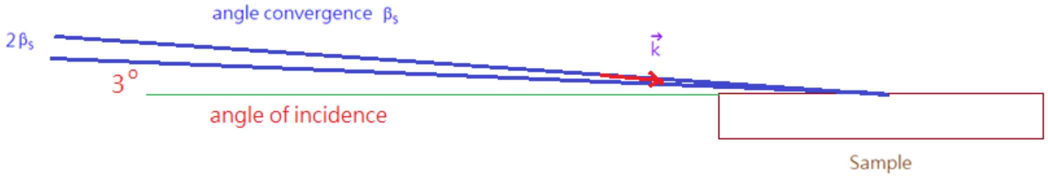
Therefore,

$$\Delta k = \frac{k\Delta E}{2E}$$

Resolved parallel to surface, for small $\beta_s$

$$\Delta k_\parallel^t \cong \frac{k\Delta E}{2E}\cos 3^o$$

(e) Spread in arrival angle over $2\beta_s$ gives spatial incoherence,



$$\Delta k_\parallel^s = k\cos(3^o + 2\beta_s) - k\cos 3^o \cong 0$$

(f) Combine uncertainties and define coherence zone diameter $\Delta X$

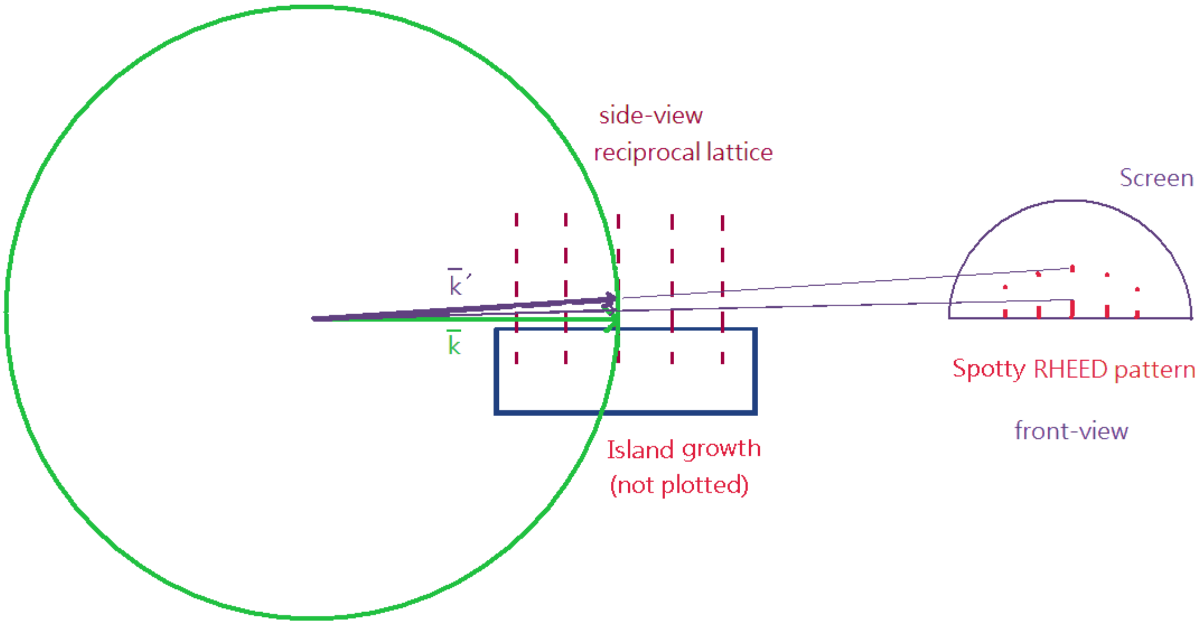
$$\Delta X \Delta k_\parallel = 2\pi$$

$$\Delta k_\parallel \cong \Delta k_\parallel^t$$

$$\Delta X \cong \frac{\lambda}{\frac{\Delta E}{2E}\cos 3^o}$$

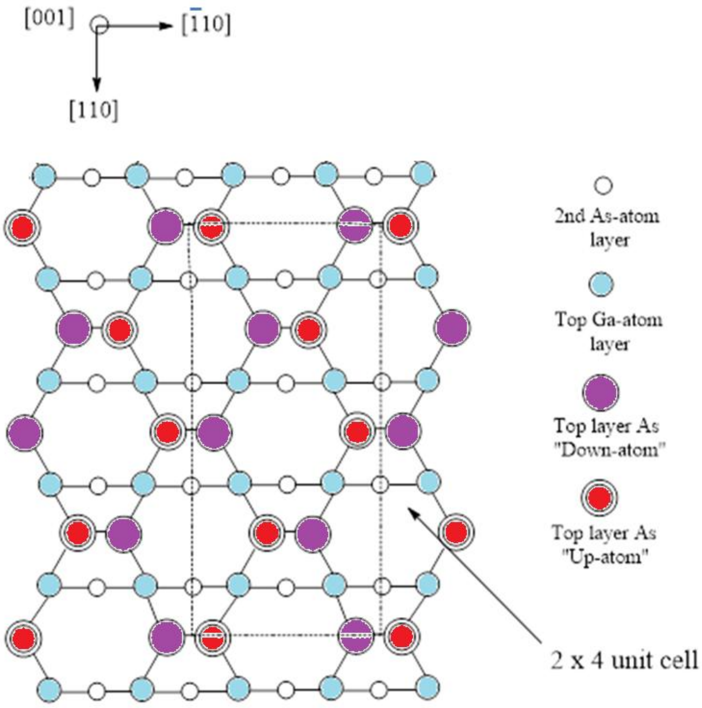
$$\Delta X \cong 180\ \ \mathrm{nm}$$

### (3) island growth



## 4. Surface reconstruction of GaAs(001)2x4

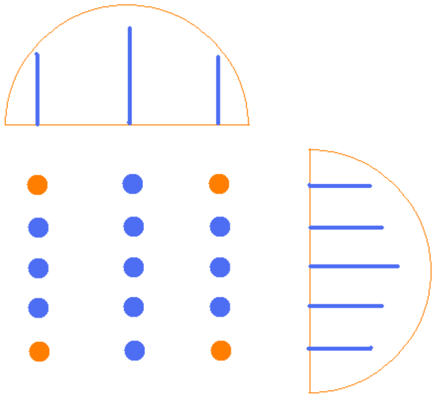
atomic model of GaAs (100) (2×4)



RHEED patterns of As-stabized GaAs(2x4) (30 KeV)

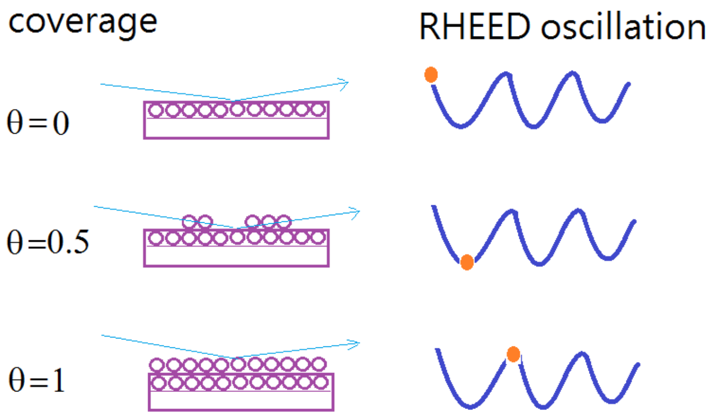
Two RHEED patterns to determine a surface reconstruction:

1) reciprocal lattice structure of GaAs(100)2x4
2) RHEED patterns along two perpendicular directions along $[\underline{11}0]$ and $[1\underline{1}0]$



## 5. RHEED oscillation

With RHEED oscillation, the epitaxial growth of a film within a precision less than a monolayer can be achieved.



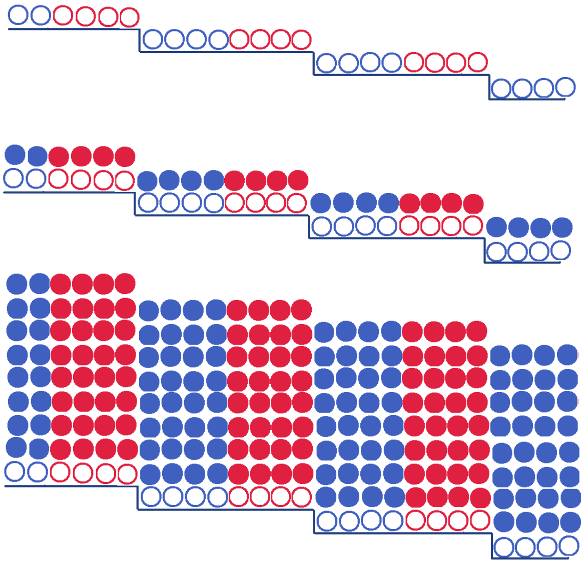
More details in the paper:
J. H. Neave *et. al.*, Applied Physics A 31, 1-8, 1981.

Mechanism of RHEED intensity oscillations during growth of a monolayer.

6. A/B tilted superlattice ( Prof. P. M. Petroff)

coverage $\theta = 0.5$ for A and B

growth sequence of the A/B tilted superlattice:



More details in the paper:

P. M. Petroff, A. C. Gossard and W. Wiegmann, Applied Physic Letters 45, 620 (1984).