MBE and the low temperature, high magnetic field systems

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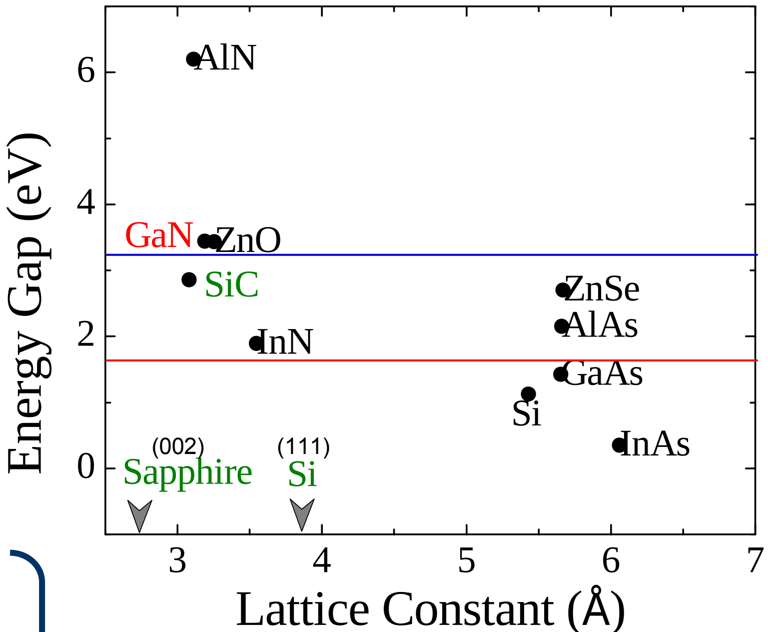
Outline

- Introduction
- RF Plasma assisted MBE system
- Hall effect measurement system
- Low temperature and high magnetic field system I— Lake shore 9705
- Low temperature and high magnetic field system II— Oxford
- Other equipments

Introduction

- Energy gap
  - AlN: 6.2 eV (200 nm)
  - GaN: 3.44 eV (360 nm)
  - InN: 1.89 eV (656 nm)
    (0.7-1.0 eV, Matsuoka *et al*., APL 2002)

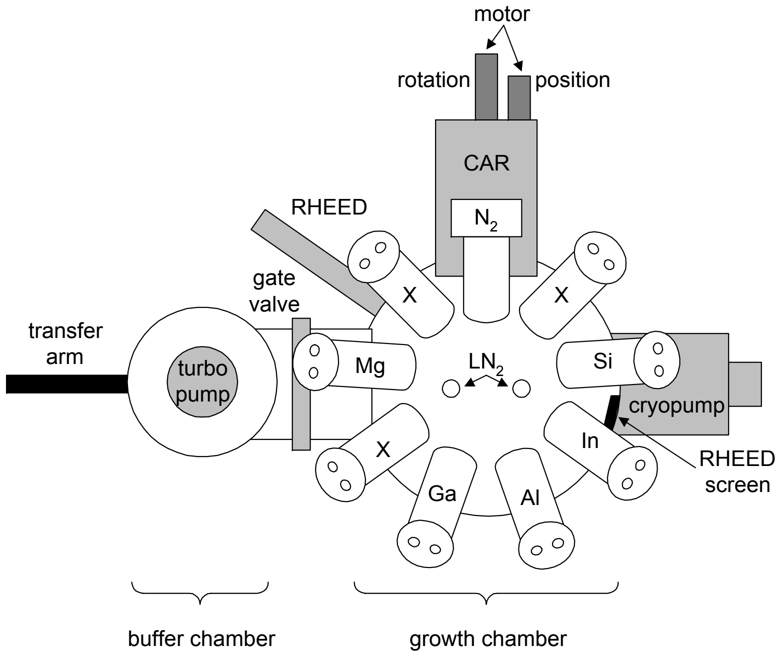


- Applications
  - Optoelectronic devices
    - solar blind and visible detectors
    - blue-ultraviolet light emitters
    - optical data storage
  - Electronic devices

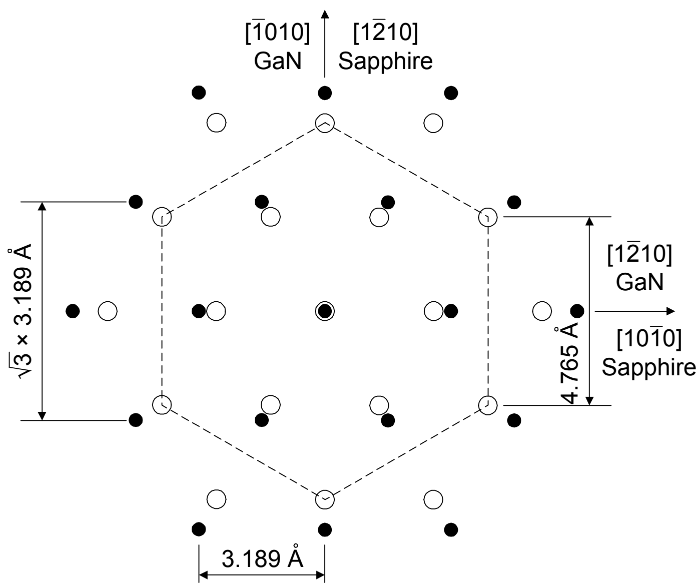
High power
High frequency
High temperature

RF Plasma assisted MBE system

Applied EPI 930



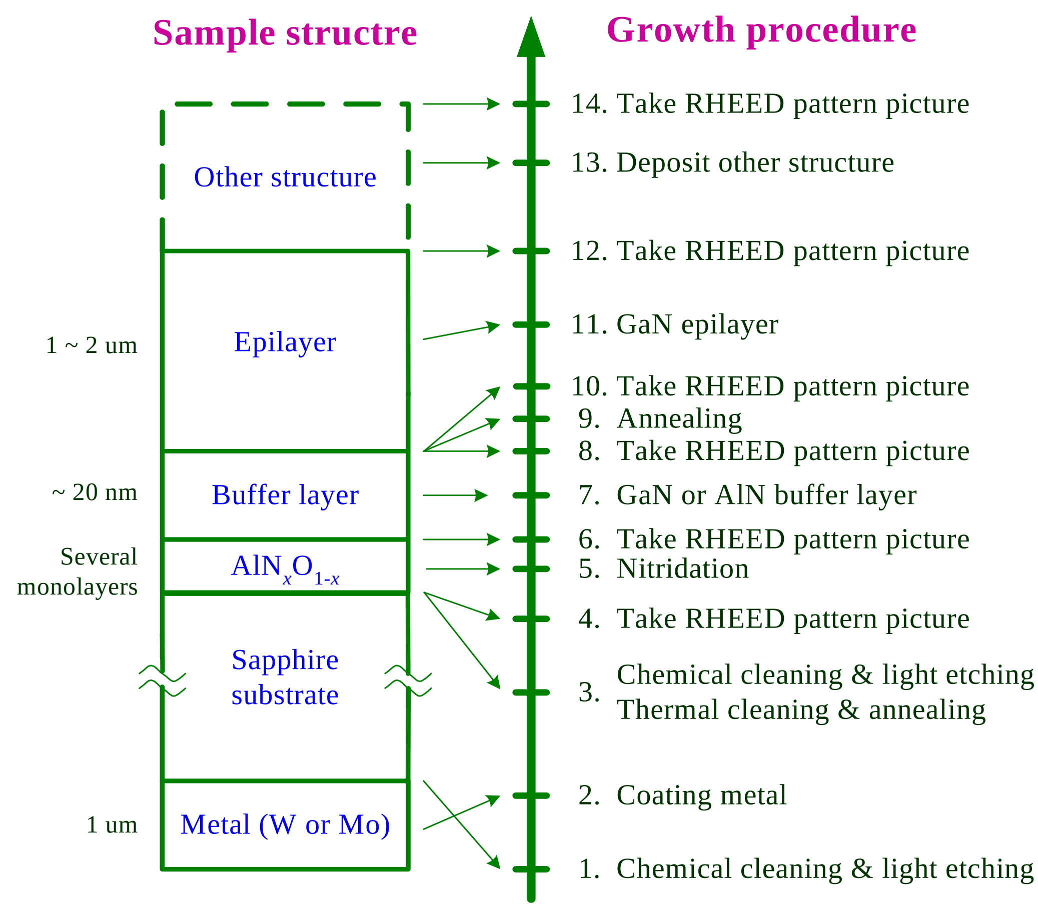
Growth procedures



(S. Nakamura *et al.*, "The blue laser diode")

Lattice mismatch=16%

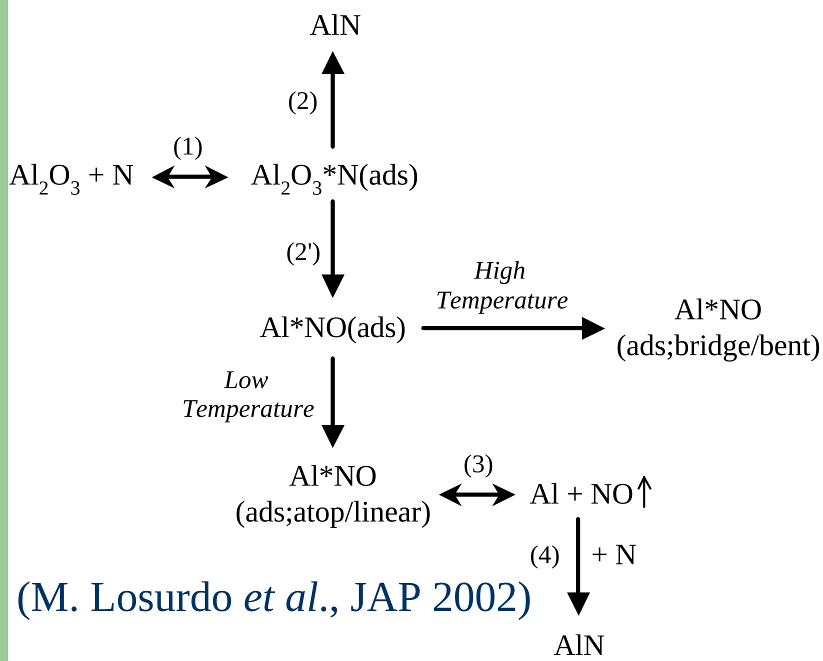
(GaN/sapphire)



Growth conditions

- Nitridation
  - Substrate temperature, RF plasma power, N_2 flux, time
- GaN or AlN buffer layer
  - Substrate temperature, RF plasma power, N_2 flux, Ga(Al) flux, N/Ga(Al) ratio, thickness
- GaN epilayer
  - Substrate temperature, RF plasma power, N_2 flux, Ga flux, N/Ga ratio, thickness

Nitridation

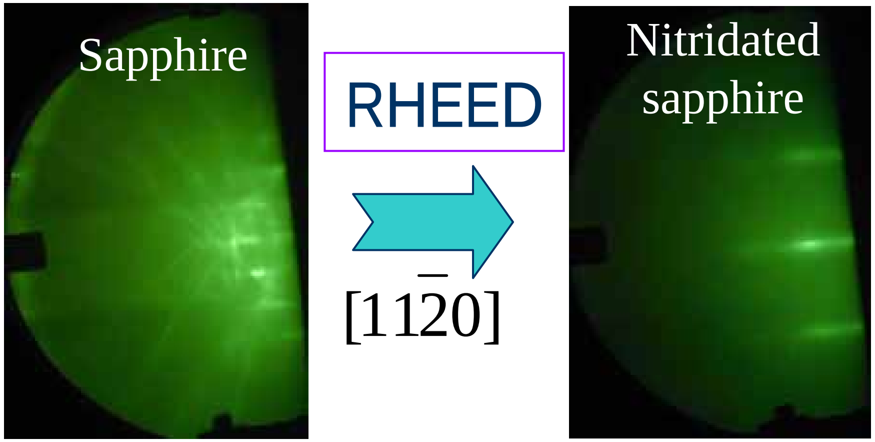


(M. Losurdo *et al.*, JAP 2002)

- (1) Adsorption equilibrium and in-diffusion of N atoms
- (2) Reactive step on an Al site
- (2') Reactive step on an O site
- (3) Adsorption/desorption equilibrium of NO in the top configuration
- (4) Further reaction on Al-site at low temperature

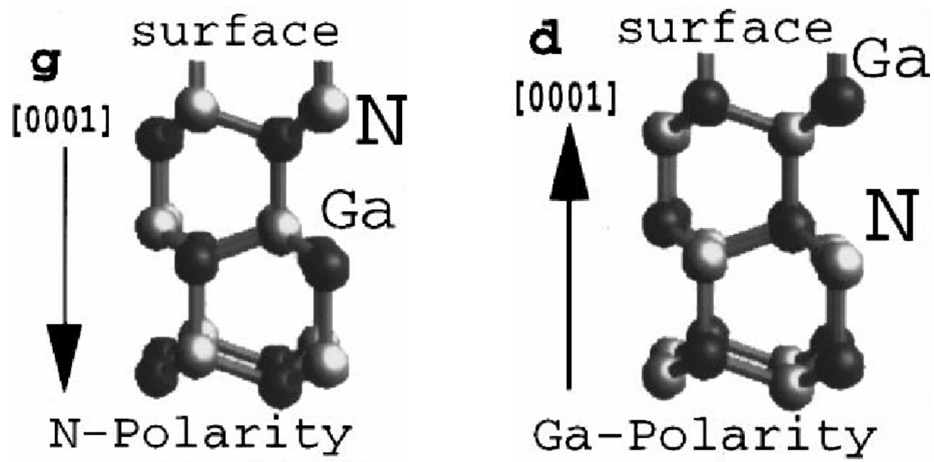
Lattice mismatch=2~3%

(GaN/AlN)

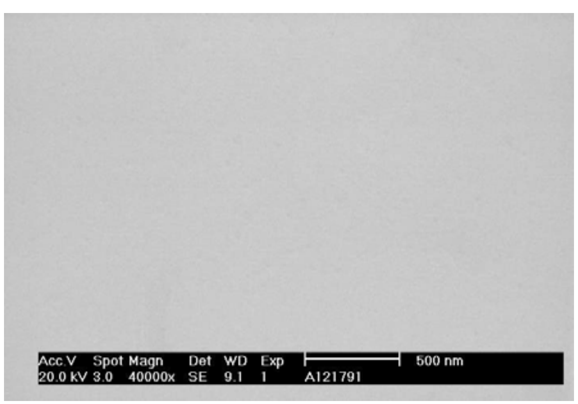


Buffer layer

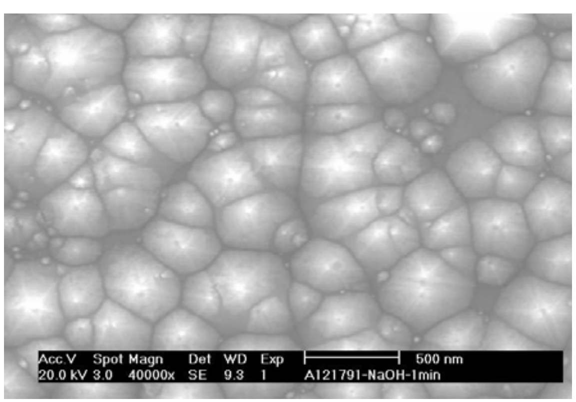
- Unstable : N-polarity
  - LT-GaN
  - LT-AlN
  - HT-GaN
- Stable : Ga-polarity
  - HT-AlN



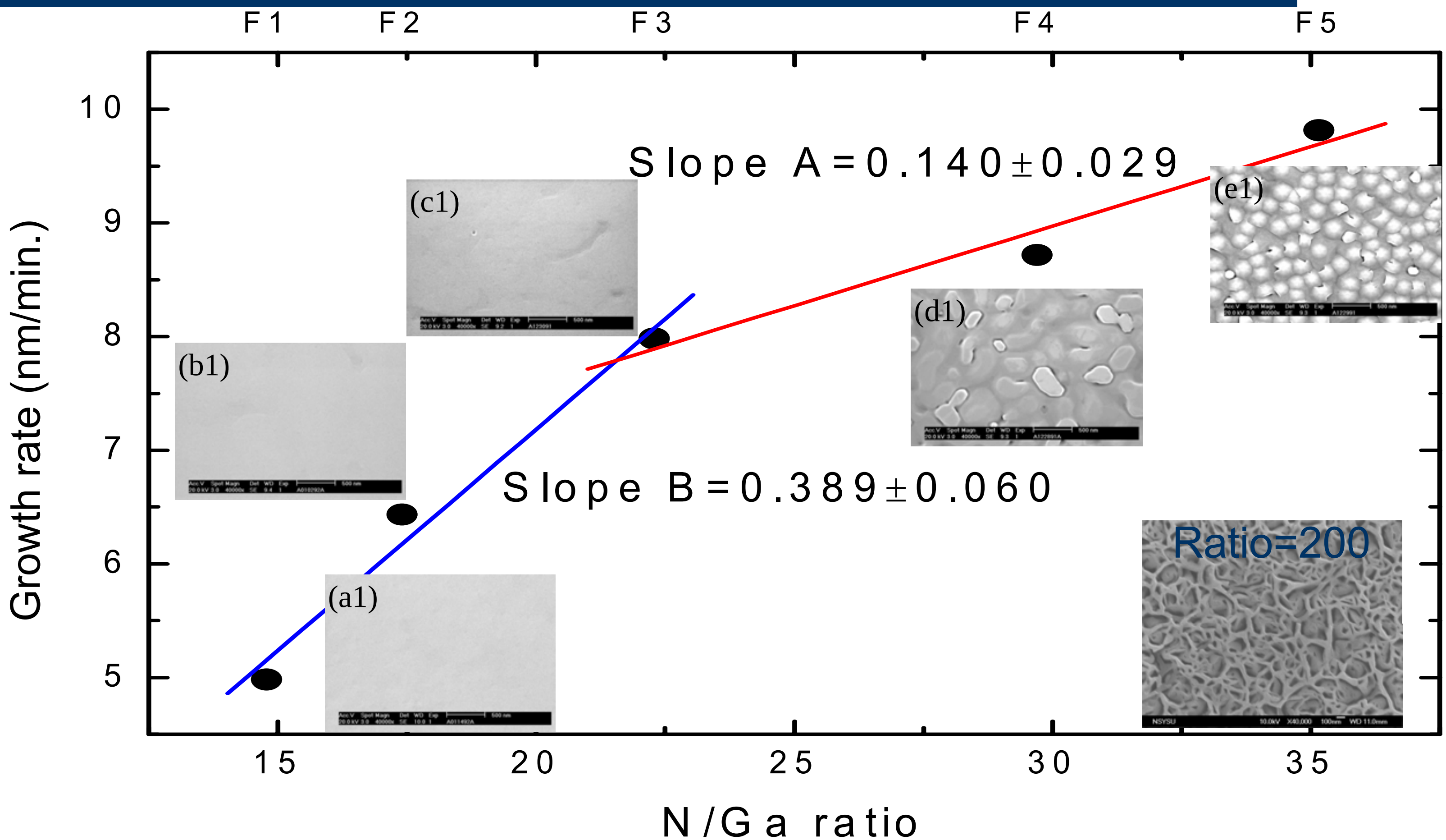
(B. Daudin *et al*., APL 1996)



after chemical wet etching (NaOH)



GaN epitaxy layer



Characteristic Measurements

1. Reflective high energy electron diffraction
2. Alpha step surface profiler
3. Field emission scanning electron microscopy
4. Transmission electron microscope
5. Atomic force microscope
6. Photoluminescence
7. Raman scattering
8. High resolution X-ray diffraction
9. Auger electron spectroscopy
10. Secondary ion mass spectrometry
11. Electron probe microanalyzer
12. Hall effect measurement
13. Shubnikov-de Haas effect and quantum Hall effect

Hall effect measurement system

- Working conditions
  - Temperature:

    Room temperature, 77 K
  - Magnetic field:

    0~500 mT

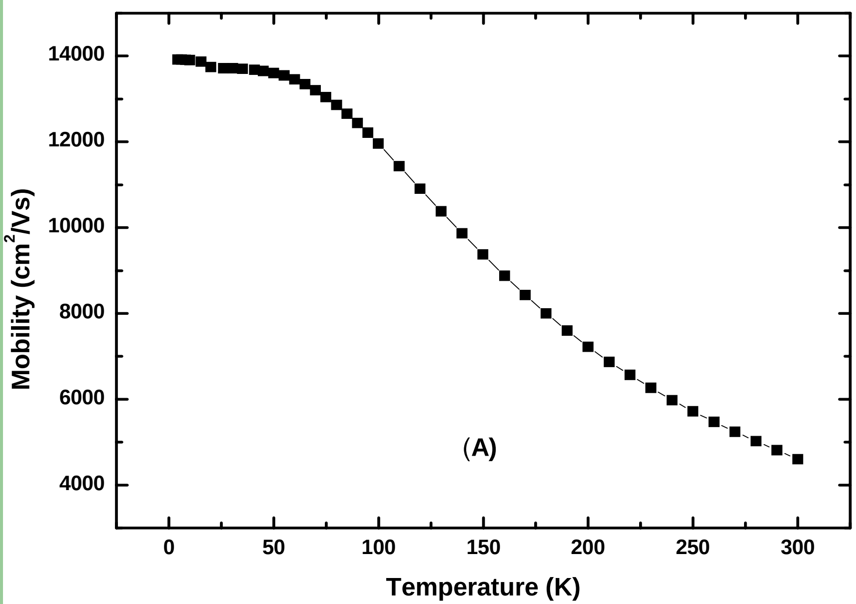
- Results
  - Mobility
  - Carrier concentration

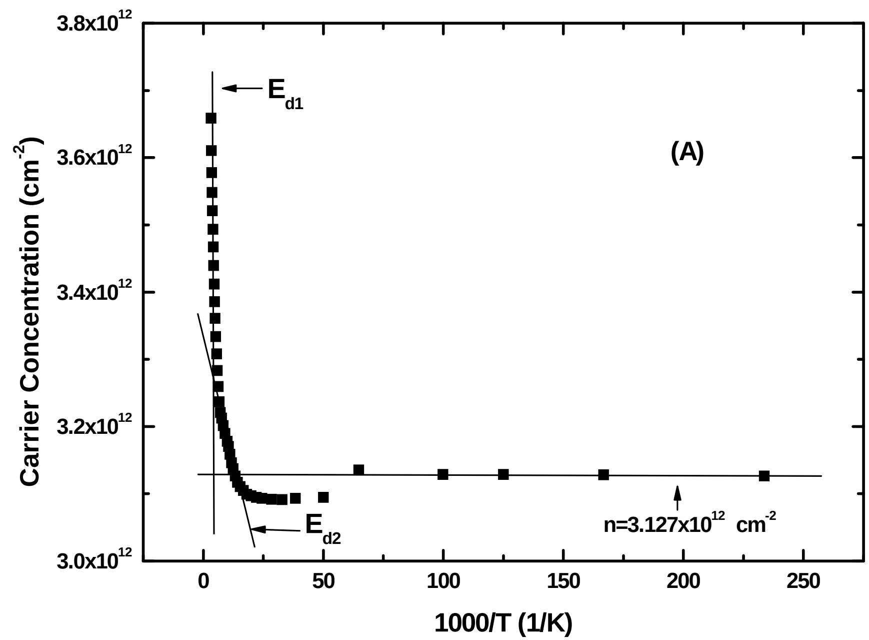
Low temperature and high magnetic field system I

Lake Shore 9705

- Working conditions
  - Temperature:
    2~400 K
  - Magnetic field:
    0~5 T
- Results
  - Mobility
  - Carrier concentration

Low temperature and high magnetic field system I

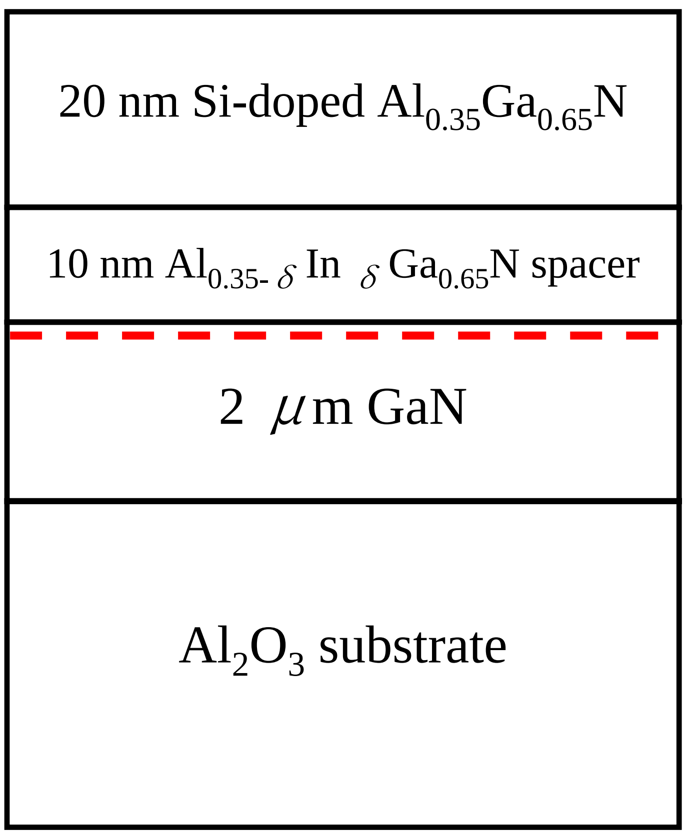


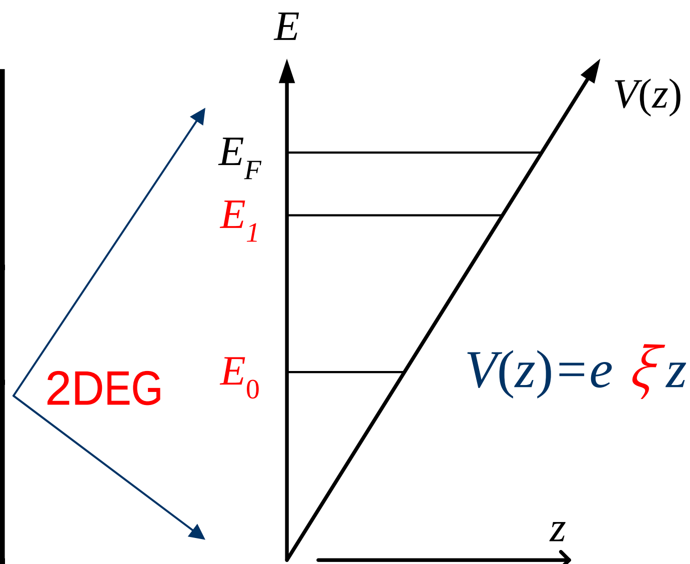


Low temperature and high magnetic field system II

- Working conditions
  - Temperature:
    - He^4 system: RT~1.2 K
    - He^3 system: RT~0.3 K
    - Dilution system: RT~0.03K
  - Magnetic field: 0~14 T
- Results
  - Shubnikov-de Haas
  - Quantum Hall Effect

Piezoelectric effect on $Al_{0.35-\delta}In_{\delta}Ga_{0.65}N/GaN$ heterostructures





For a triangular potential well confined by a electric field ξ

Si doping level of the top barrier is the same, 5×10^{18} cm^{-3}

Sample G1, $\delta = 0$

Sample G2, $\delta < 0.01\%$

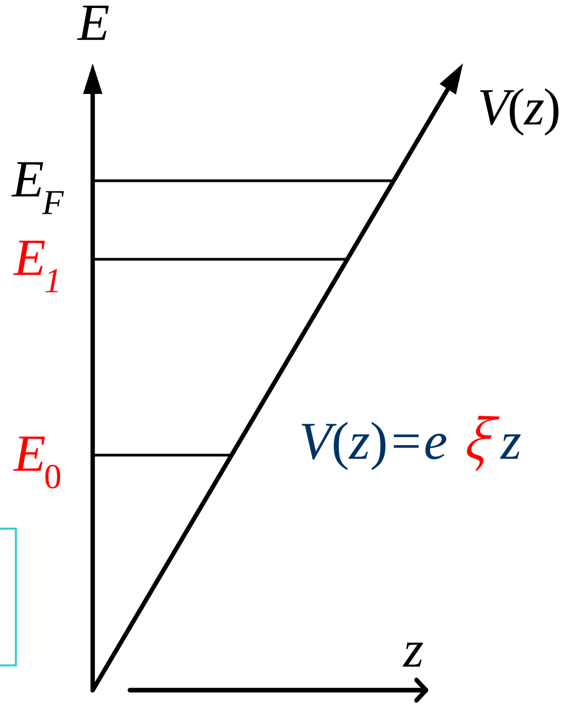
Piezoelectric effect on $Al_{0.35-\delta}In_{\delta}Ga_{0.65}N/GaN$ heterostructures

$$-\frac{\hbar^2}{2m^*}\frac{d^2}{dz^2}\psi(z)+e\xi z\psi(z)=E_i\psi(z)$$

$$E_i=\left(\frac{\hbar^2}{2m^*}\right)^{\frac{1}{3}}\left(\frac{3\pi e\xi}{2}\right)^{\frac{2}{3}}\left(i+\frac{3}{4}\right)^{\frac{2}{3}}$$

$$\Delta E_i=E_F-E_i=\frac{\pi\hbar^2 n_i}{m_i^*}$$

$m^*(E)= m_b[1 + 2E/E_g]$
$\sim 0.215\ m_0$



From SdH measurement

$$f_i=\frac{hn_i}{2e}$$

Piezoelectric effect on $Al_{0.35-\delta}In_{\delta}Ga_{0.65}N/GaN$ heterostructures

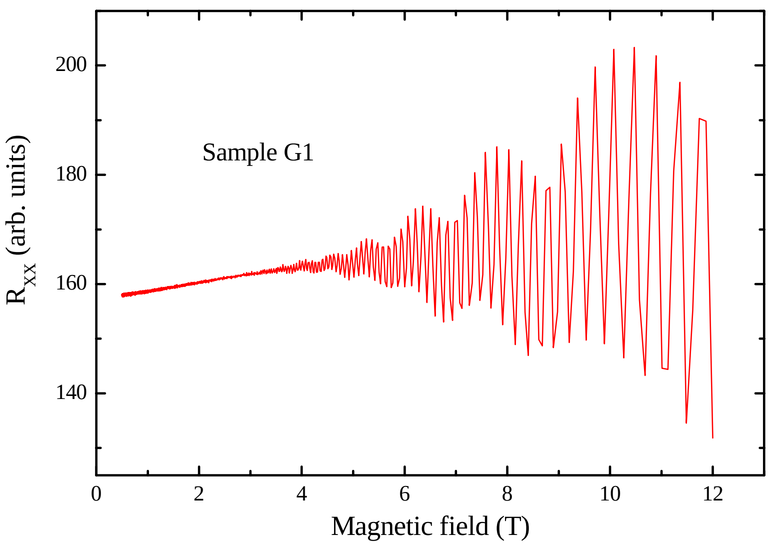
$$\Delta E_{i-j} = \Delta E_i - \Delta E_j$$

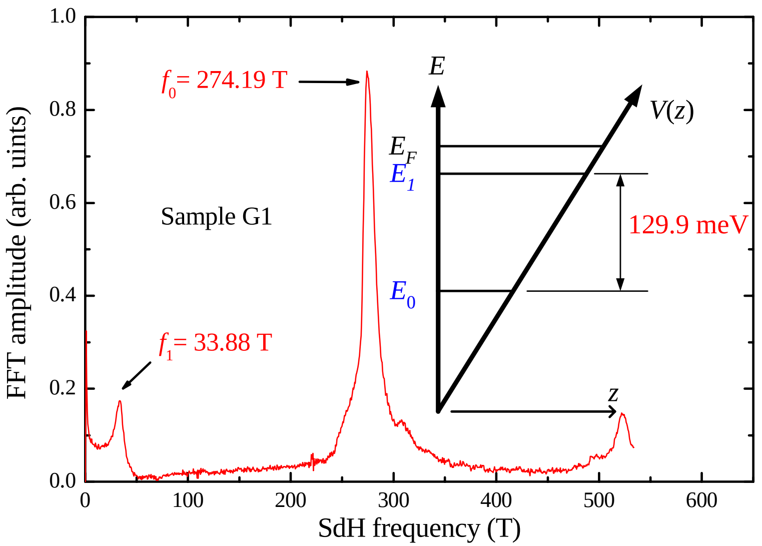
$$= (E_F - E_i) - (E_F - E_j) = E_j - E_i$$

$$= \left(\frac{\hbar^2}{2m^*}\right)^{\frac{1}{3}} \left(\frac{3\pi e \xi}{2}\right)^{\frac{2}{3}} \left[\left(\boxed{j} + \frac{3}{4}\right)^{\frac{2}{3}} - \left(\boxed{i} + \frac{3}{4}\right)^{\frac{2}{3}}\right]$$

$$\Delta E_{0-1} = \left(\frac{\hbar^2}{2m^*}\right)^{\frac{1}{3}} \left(\frac{3\pi e \xi}{2}\right)^{\frac{2}{3}} \left[\left(1 + \frac{3}{4}\right)^{\frac{2}{3}} - \left(0 + \frac{3}{4}\right)^{\frac{2}{3}}\right]$$

Piezoelectric effect on $Al_{0.35-\delta}In_{\delta}Ga_{0.65}N/GaN$ heterostructures



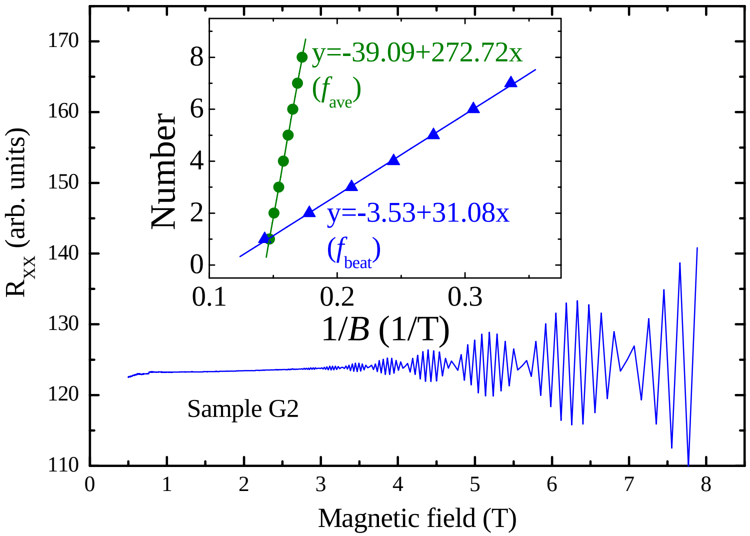


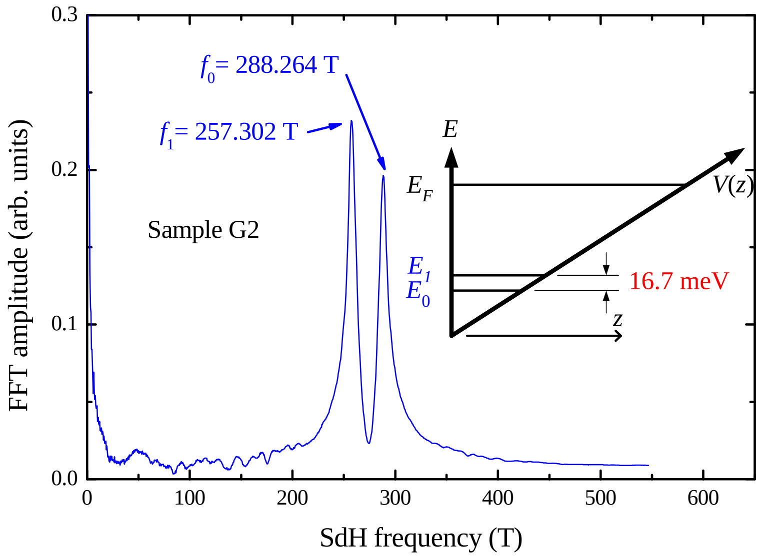
$$\begin{cases} f_0 = 274.19\ \text{T} \\ f_1 = 33.88\ \text{T} \end{cases} \Rightarrow \begin{cases} n_0 = 1.330 \times 10^{13}\ \text{cm}^{-2} \\ n_1 = 1.643 \times 10^{12}\ \text{cm}^{-2} \end{cases}$$

$$\begin{cases} \Delta E_0 = 148.1\ \text{meV} \\ \Delta E_1 = 18.2\ \text{meV} \end{cases} \Rightarrow \Delta E_{0\text{-}1} = 129.9\ \text{meV}$$

$$\xi = 4.75 \times 10^5\ \text{V/cm}$$

Piezoelectric effect on $Al_{0.35-\delta}In_{\delta}Ga_{0.65}N/GaN$ heterostructures



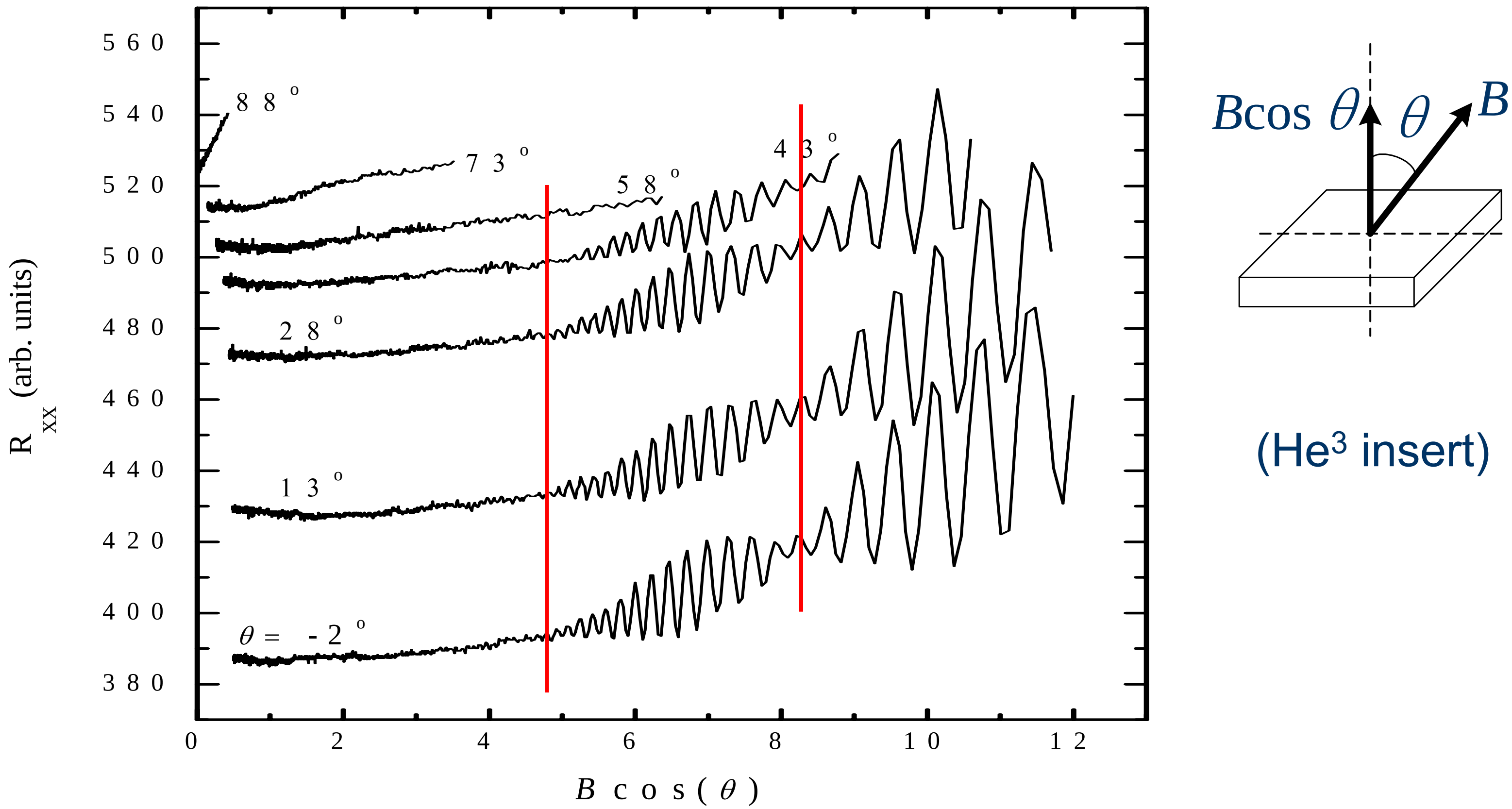


$$\begin{cases} f_0 = 288.26\ \text{T} \\ f_1 = 257.30\ \text{T} \end{cases} \Rightarrow \begin{cases} n_0 = 1.398 \times 10^{13}\ \text{cm}^{-2} \\ n_1 = 1.248 \times 10^{13}\ \text{cm}^{-2} \end{cases}$$

$$\begin{cases} \Delta E_1 = 155.7\ \text{meV} \\ \Delta E_2 = 139.0\ \text{meV} \end{cases} \Rightarrow \Delta E_{0\text{-}1} = 16.7\ \text{meV}$$

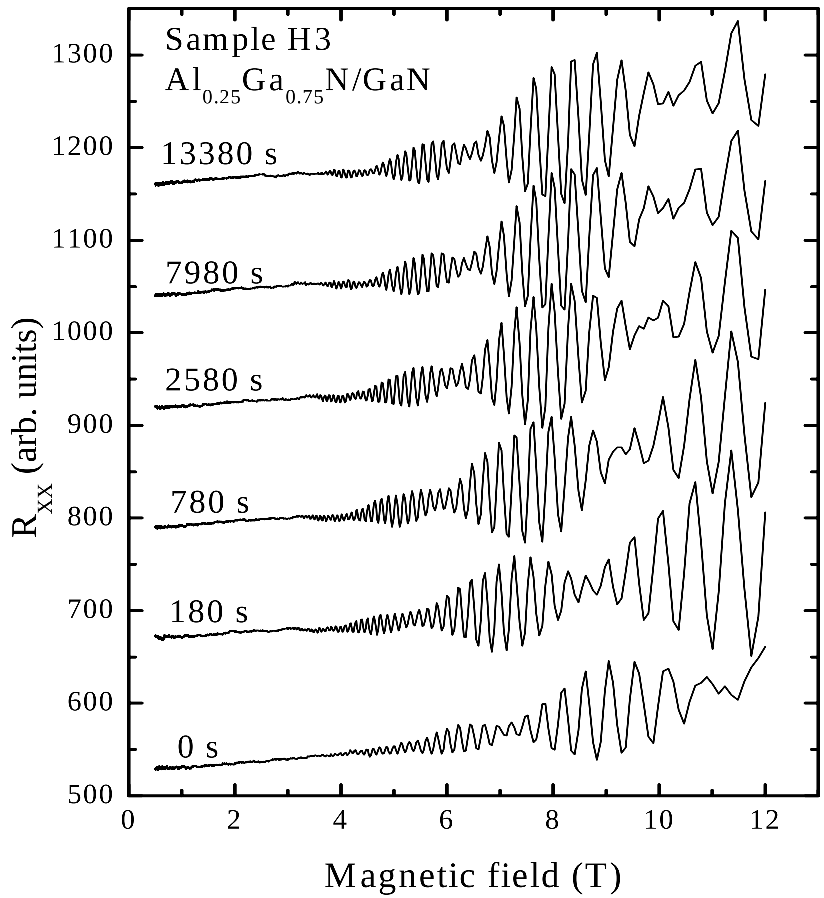
$$\xi = 2.19 \times 10^{4}\ \text{V/cm}$$

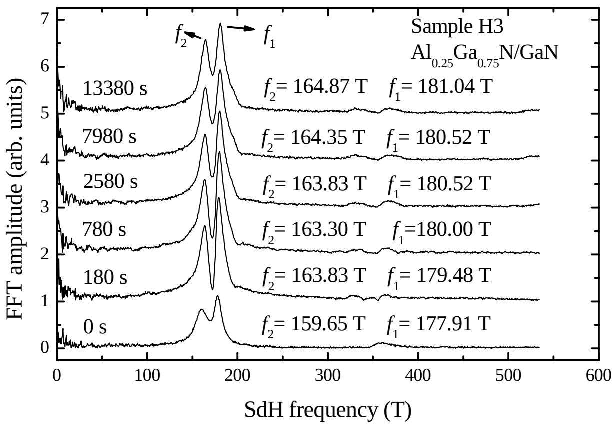
Other examples

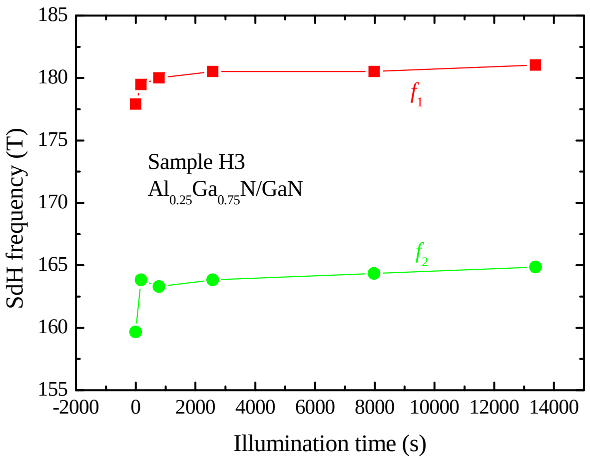


(He³ insert)

Other examples







E-beam evaporation system

- Metal
  - Au
  - Al
  - Mo
  - W
  - Ti
  - Ni

Thanks for your attention.