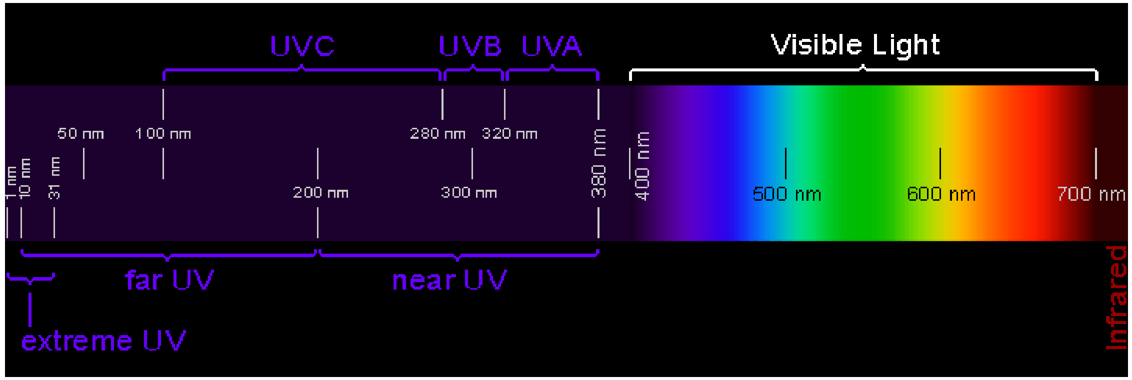
Topic 19

19 Ultraviolet Light emitting diodes (UV-LEDs)

- 19.1 Introduction
- 19.2 Categories of UV light
- 19.3 Applications of UV light
- 19.4 Optical sources of UV light
- 19.5 Major advantages of UV-LEDs
- 19.6 UV LED structures and design
- 19.7 Current challenges

Major applications of UV light

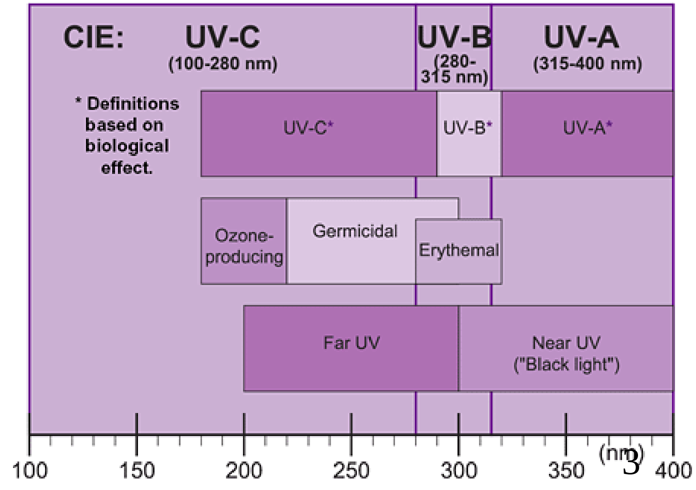


255 / 365 nm	**Micro-contamination Detection**
280 nm	**Non-line-of-sight Communications**
225 - 280 nm	**Water pollution**
365 - 375 nm	**UV Curing**
265 - 405 nm	**Scientific Analysis**
365 - 385 nm	**Banknote verification**
310 - 405 nm	**Phototherapy**
340 - 405 nm	**Crime Scene Inspection**
395 - 405 nm	**UV Dental Whitening**

Categories of UV radiation

Ultraviolet A	UVA	400 – 315 nm	Black-light, not absorbed by the ozone layer
Ultraviolet B	UVB	315 – 280 nm	medium wave, mostly absorbed by the ozone layer
Ultraviolet C	UVC	280 – 100 nm	short wave, germicidal, NLOS completely absorbed by the ozone layer and atmosphere

Ultraviolet C: 280nm is best for NLOS



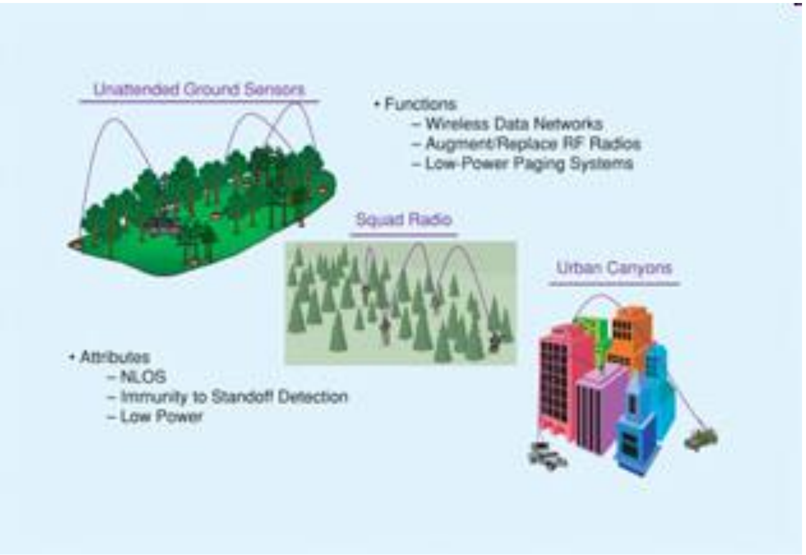
Categories of UV radiation

UV-A: Long wave UV, also known as blacklight, responsible for skin tanning, is also used in medicine to treat certain skin disorders.

UV-B: A small, but dangerous part of sunlight. Most solar UV-B is absorbed by the diminishing atmospheric ozone layer. Prolonged exposure could result in unhealthy effects on the skin and eyes.

UV-C: shortwave UV and used for air, surface and water disinfection. Unintentional overexposure to UV-C causes skin redness and eye irritation, but does NOT cause skin cancer or cataracts.

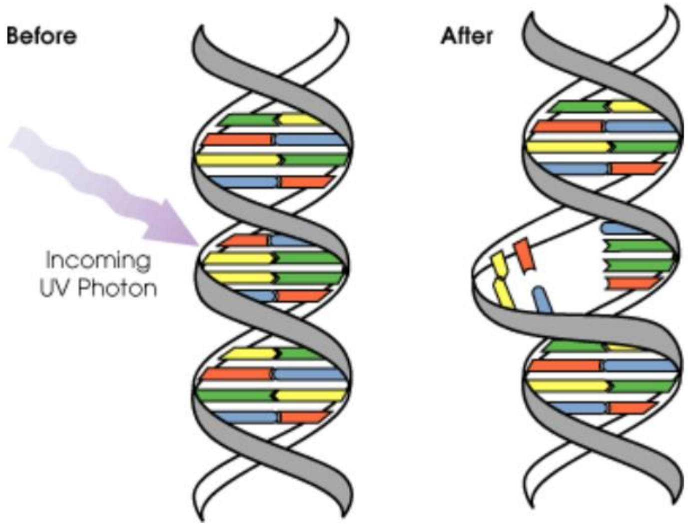
Applications: (i) Non-line-of-sight Communication



Non-Line-of-sight (NLOS) communications is the option that would be interesting for these cases. It is a short range communication system, depending on a number of factors

- It requires a large number of scattering centres for signal photons, which can generate **Non-Line-of-sight** paths for signals.
- Less sensitivity to solar and other background interference, leading to less impact on the signal to noise ratio of a detector.
- Short-range communications: strong absorption of signal beyond a certain range for security purpose

Applications: (ii) water purification



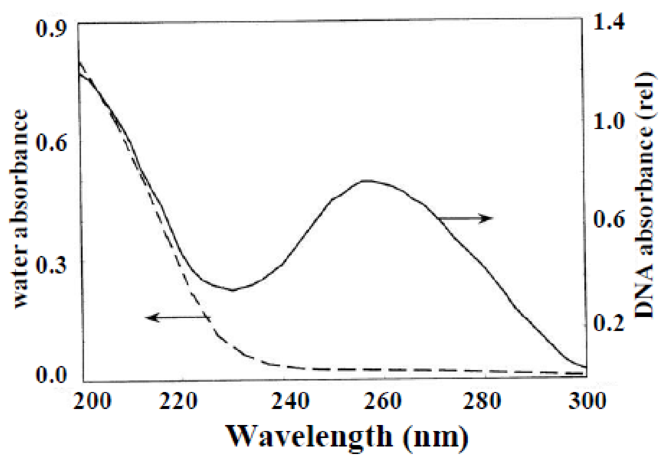


Figure 1 Typical absorption spectra of water and DNA

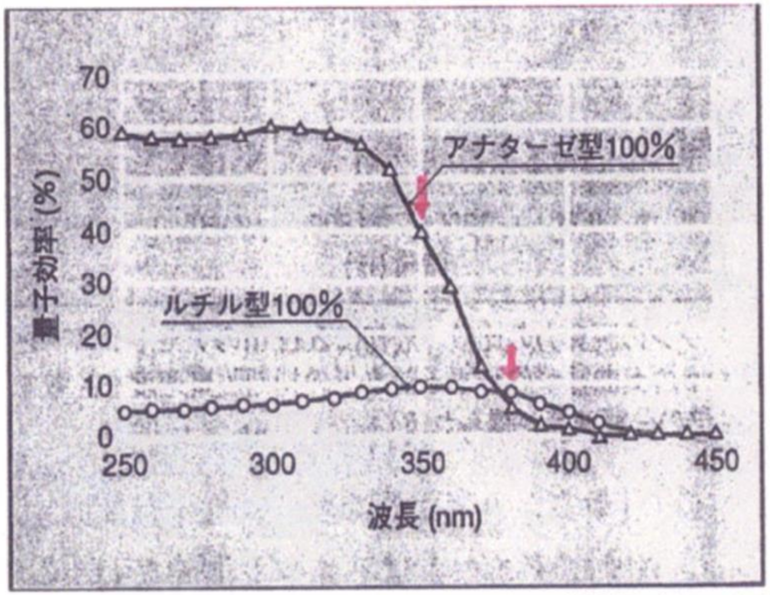
UV Disinfection Process:

- **UV photons harm the DNA molecules of microorganisms.**
- **In one common damage event, adjacent bases bond with each other, instead of across the "ladder".**
- **The distorted DNA molecule does not function properly.**

- **Efficient UV lighting source: 250-260 nm**

- **UV water purification: simple and no side effect**

Applications: (iii) Environmental protection



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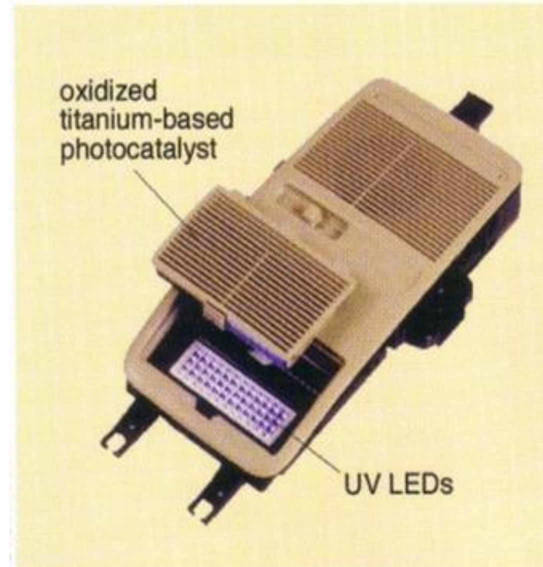
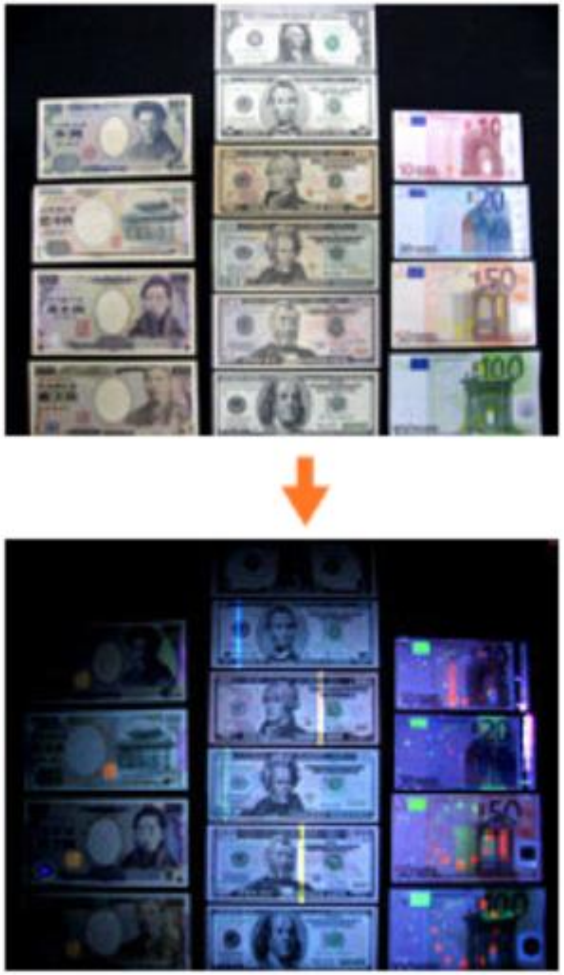


An photocatalyst purifier using Toyoda Gosei LEDs has been used in air conditioning systems in Toyota cars.

- Air-purifier: decompose organic substances in the air into water and carbonic acid using a **titanium oxide as an optical catalyst**, which works well only under the illumination of **UV light**
- UV: < **350 nm**

Applications: (iv) Banknote verification

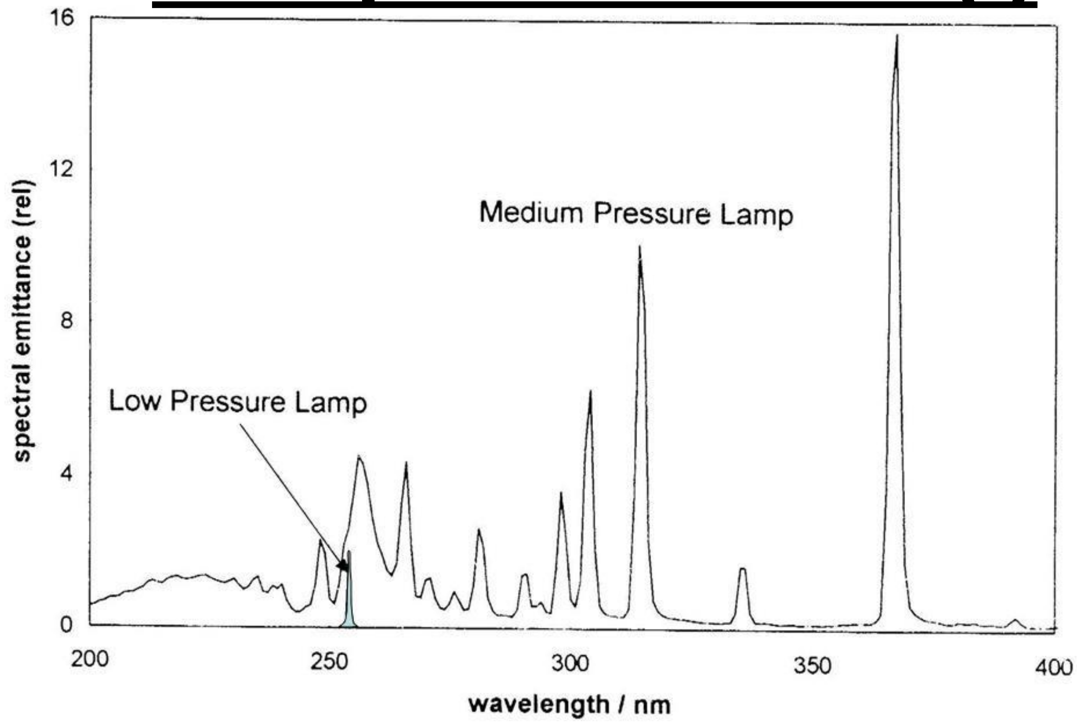


(At irradiation of UVLED)

(Closeup)

UV wavelength: 365 - 385 nm

UV optical sources (i)

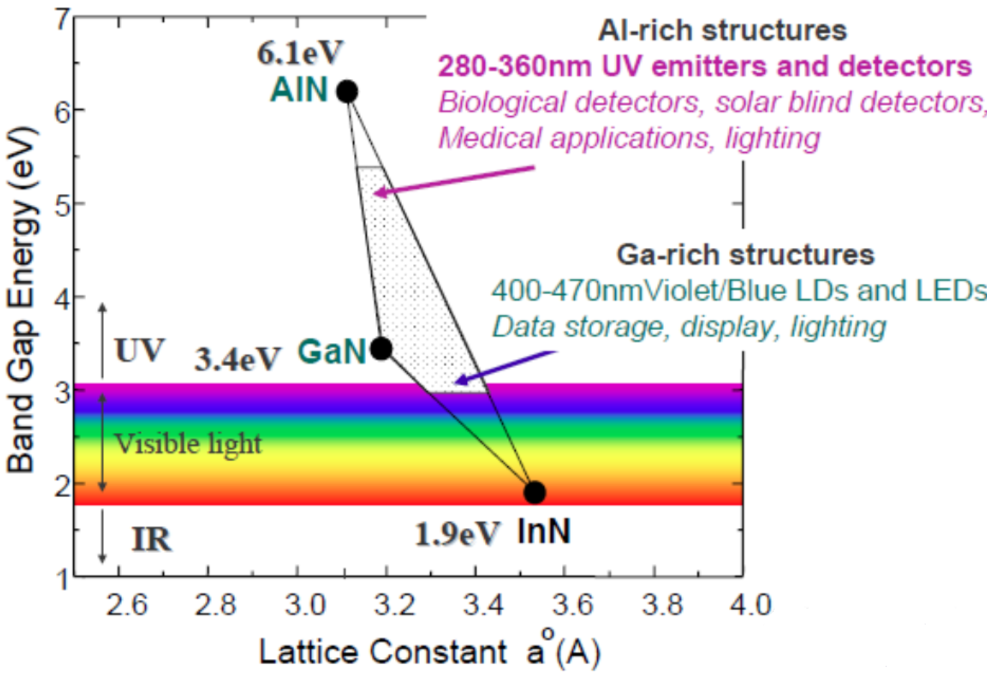


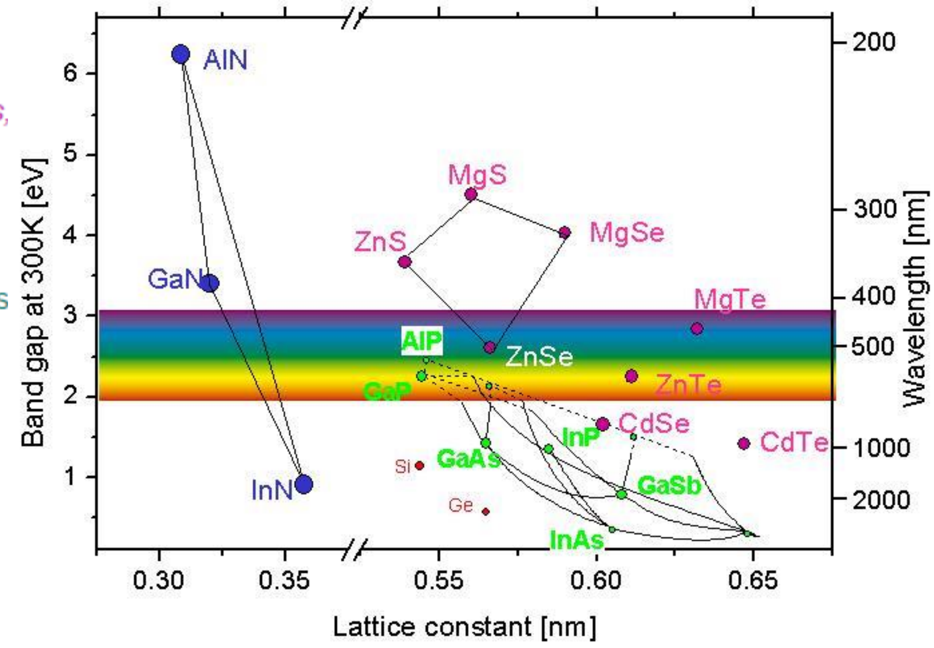
UV light sources:

(1) Predominated by a mercury lamp at discrete wavelengths.

(2) Other practical UV sources with more continuous emission spectra include xenon arc lamps (commonly used as sunlight simulators), deuterium arc lamps, mercury-xenon arc lamps, metal-halide arc lamps, and tungsten-halogen incandescent lamps.

UV optical sources (ii): UV-LEDs





AlGaN: **this is the only option to obtain <280 nm (~4.42 eV)**

Major advantages of UV-LEDs

	LED	Deuterium lamp	Xenon flash lamp	Mercury Lamp
Spectrum	Single Peak	Broad spectrum	Broad spectrum	Broad spectrum
Stability of Light Output	Excellent	Good	Relatively Poor	Relatively Poor
Warm Up Time	Instantaneous	20-30 minutes	Instantaneous	1-15 minutes
Thermal Effect on Samples	None*	Heat sensitive samples can be affected	None	Heat sensitive samples can be affected
Overall Cost of Ownership	Low**	High	High	Low
Drive Electronics	Simple	Complex	Complex	Complex
Safety	Low voltage, cold light source with shock resistant construction	Hot bulb surface with high voltage power supply	High voltage supply with ignition and sparking risk	High voltage supply and contains mercury in fragile quartz envelope

Source: Crystal IS

Design of UV-LEDs

- Equation used to estimate Al **Composition of AlGaN for UV wavelength required:**

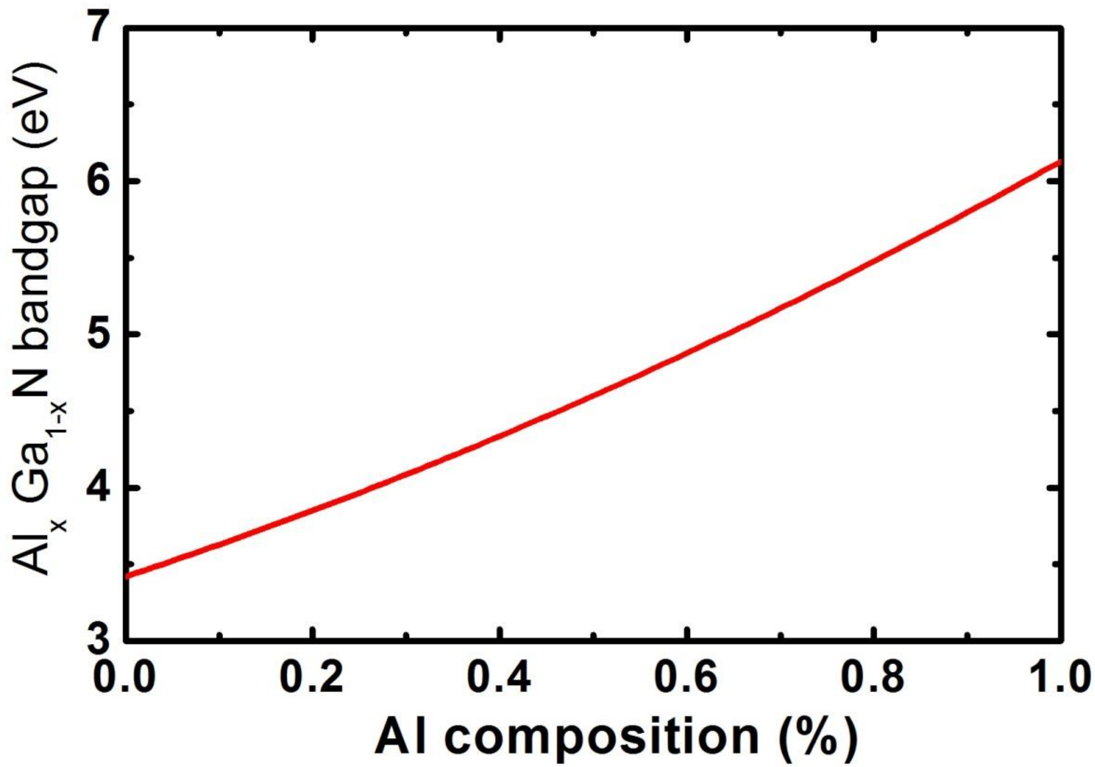
$$E_{AlGaN}=x^*E_{AlN} + (1\text{-}x)^*E_{GaN} – x(1\text{-}x)^*b$$

E_{AlN} : Bandgap of AlN, 6.13 eV at room temperature
E_{GaN}: Bandgap of GaN, 3.42 eV at room temperature
b: Bowing parameter, 0.7eV

Do it yourself: Al composition for 280 nm (~4.42 eV)

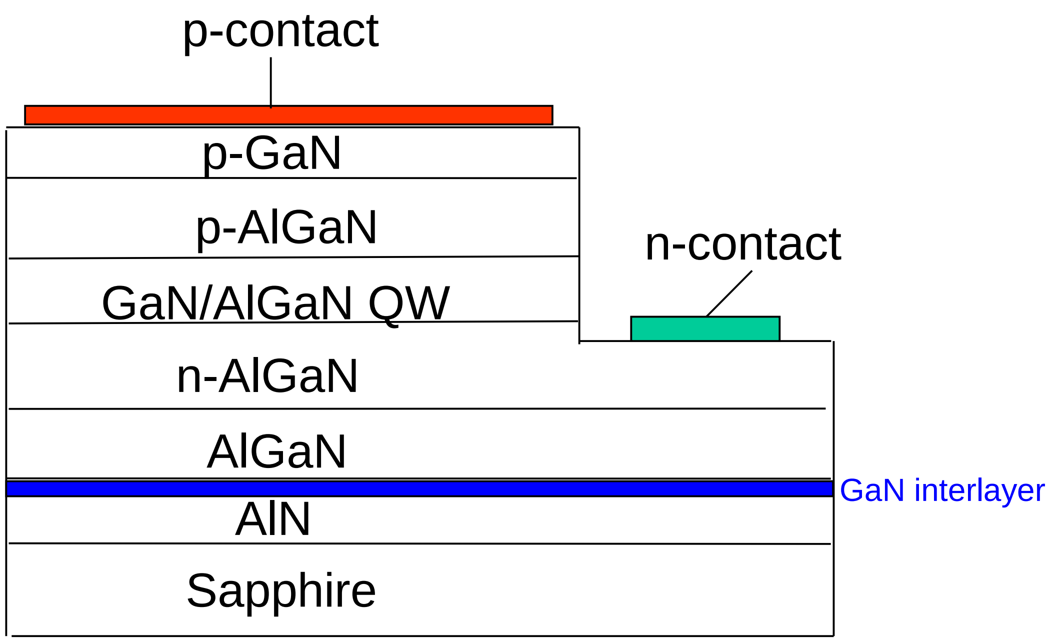
UV optical sources: UV-LEDs

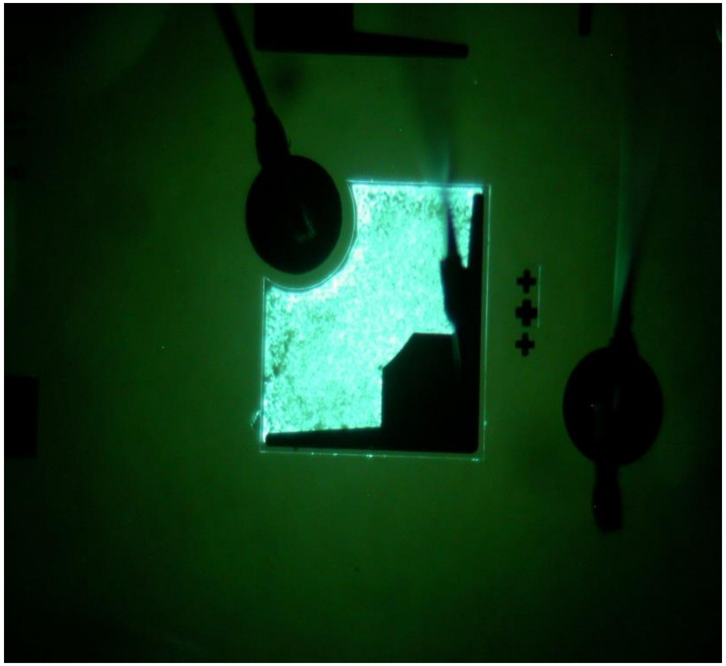
$$E_{AlGaN}=x*E_{AlN} + (1-x)*E_{GaN} - x(1-x)*b$$



Al composition for <280 nm (~4.42 eV): > 43%

Fabrication of 340 nm UV-LEDs



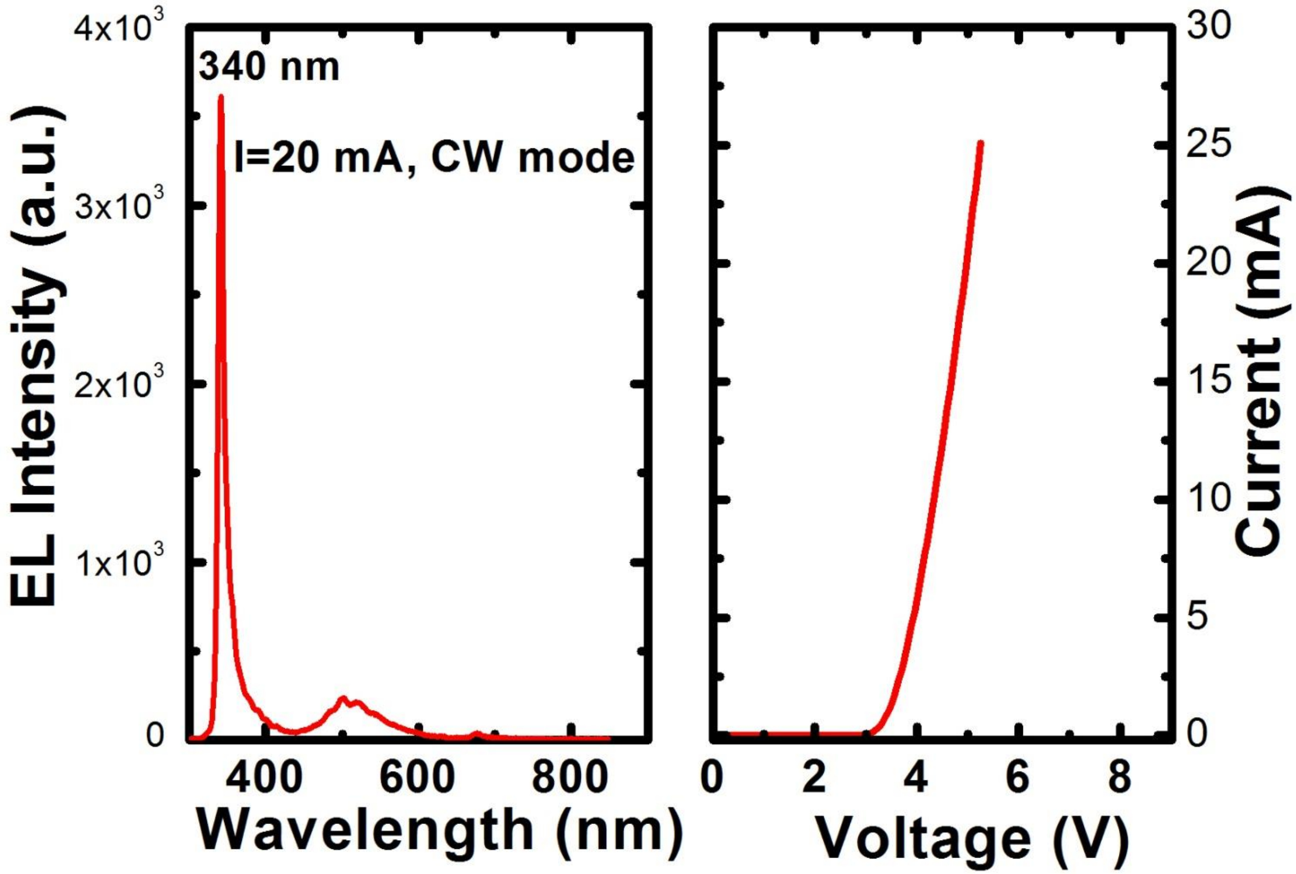


Schematic structure of 340 nm UV-LED

Optical image of a fabricated UV-LED

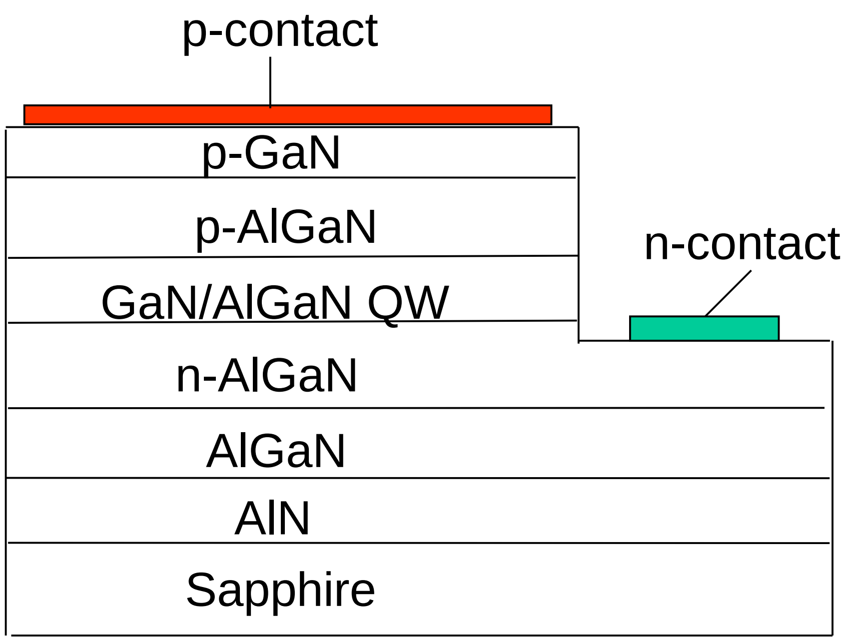
Sheffield team: Developed a simple approach to achieving 340 nm UV LEDs with good performance

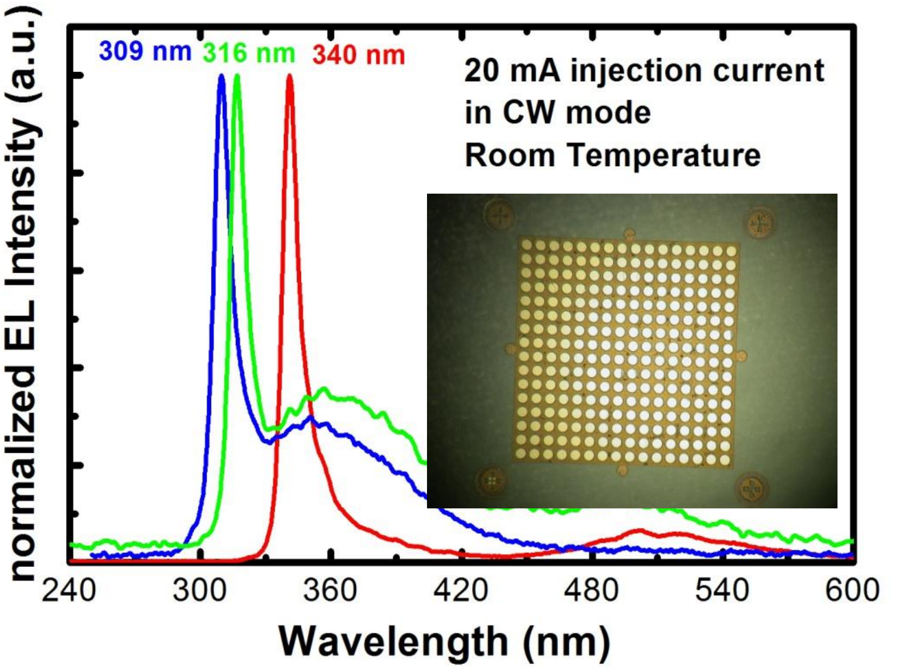
340 nm LED Characteristics



- UV-LED with interlayer: V_f = 5 V @ I_f = 20 mA
- Significantly improved I-V characteristic and output power

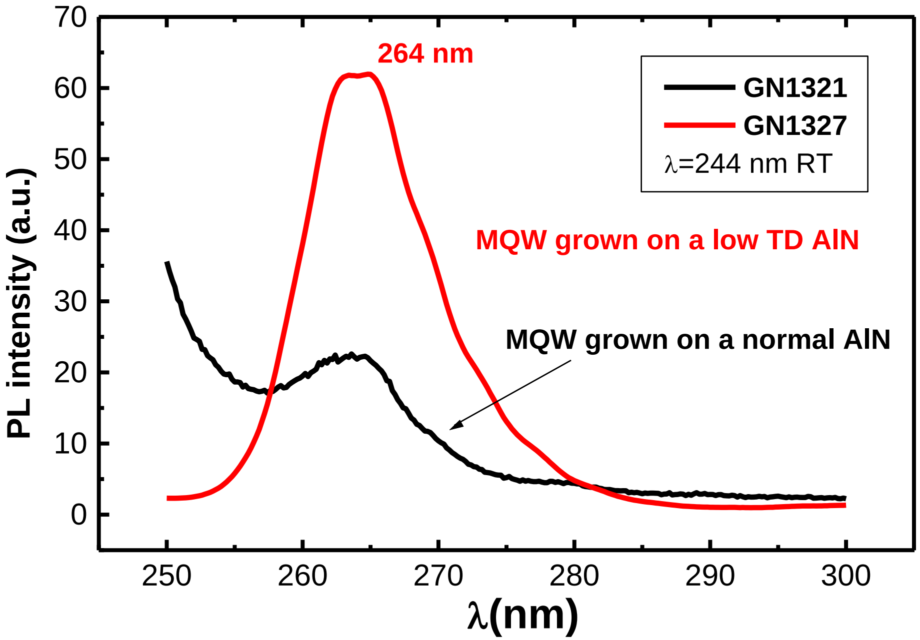
310-340 nm UV LEDs

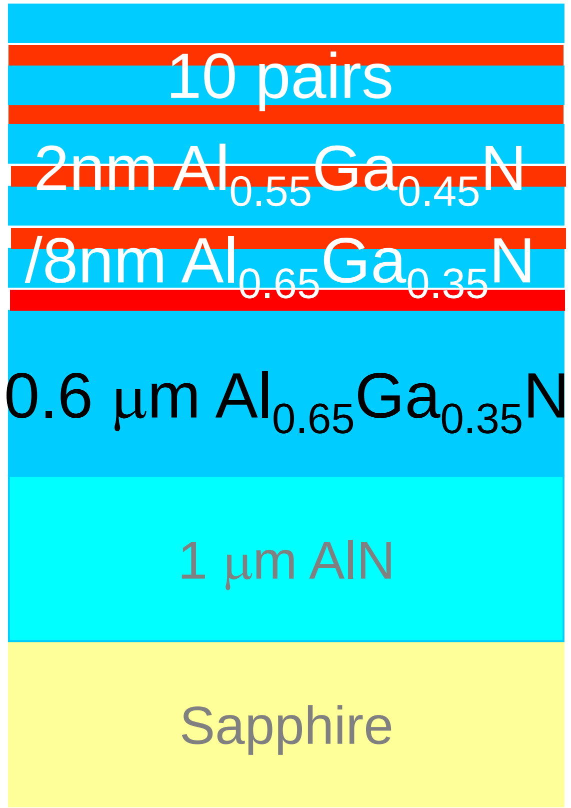




- **Sheffield team: also achieved 310-340 nm**
- **Further increase Al composition in MQWs**
- **Challenge in pushing toward shorter wavelength**

Sub 280 nm UV emission





Sheffield team: Developing a patented technology among only a few groups to achieve such a short wavelength

Current challenges

- **Technological challenges:**

  III-nitride Growth------ lattice mismatched hetero-epitaxy

  Lack of suitable and affordable substrates: AlN substrates

  Difficulty in growth of AlN or AlGaN with high Al composition as a result of current limit in heater elements used for MOCVD

- **Scientific challenges**

  (1) Polarization induced self-built electric fields

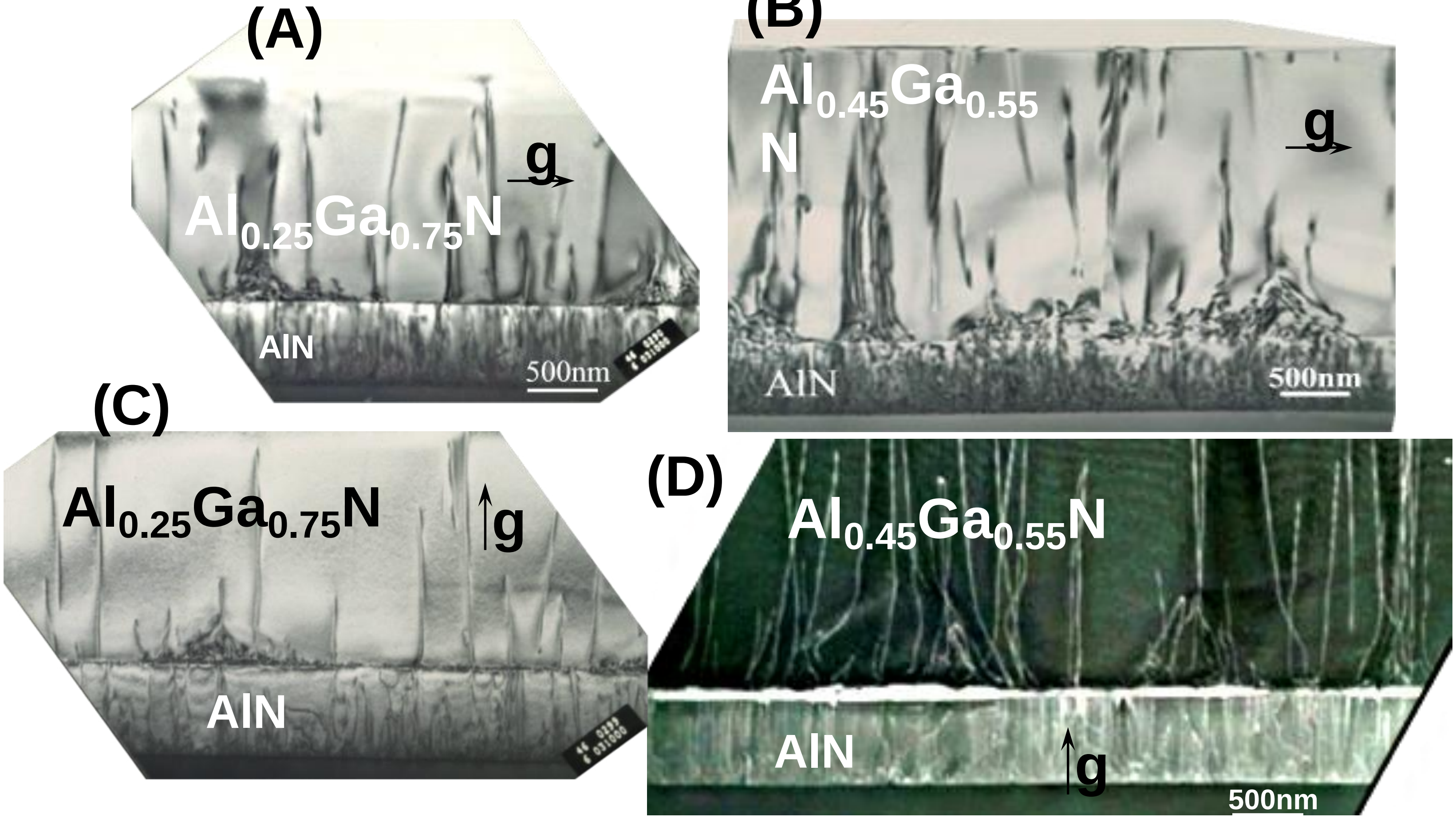
  (2) P-type activation energy increases dramatically with increasing Al composition, leading to difficulty in obtaining conductive p-Al(Ga)N

  (3) Difficulty in device fabrication, such as p-contact

Effect of Al fraction on dislocations

340nm LED

310 nm LED



- **Dislocation density increases with increasing Al composition.**

T19 Tutorial Questions

- Describe category of UV lights
- Explain UVA, UV B and UV C and their properties
- State how to manufacture UV LEDs
- Describe the major advantages of UV LEDs compared with other UV sources
- Explain how to design a UV LED structure in order to obtain Al composition of AlGaN to meet requirements with a specific wavelength
- Current challenges in fabrication of UV-LEDs