POTENSI DAN TANTANGAN REKAYASA MATERIAL SEMIKONDUKTOR ZNO UNTUK APLIKASI OPTOELEKTRONIKA

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24 Januari 2024, 15.00 WIB

IWAN SUGIHARTONO

ANGGOTA PSI CABANG JAKARTA-BANTEN

PROFIL PEMBICARA

Dosen Fisika FMIPA Universitas Negeri Jakarta
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Selected Publications

1. Structure and optical properties of La-doped ZnO thin films at room temperature
   I Sugihartono, B Soegijono, E Handoko, TS Tiam, AA Umar
   Processing and Application of Ceramics 17 (2), 107-112 (2023)
2. Influence of Co incorporation on morphological, structural, and optical properties of ZnO nanorods
   synthesized by chemical bath deposition
   I Sugihartono, N Purwanto, D Mekarsari, M Diantoro, R Fahdiran, et al
   Advances in Materials Research 12 (3), 179 (2023)

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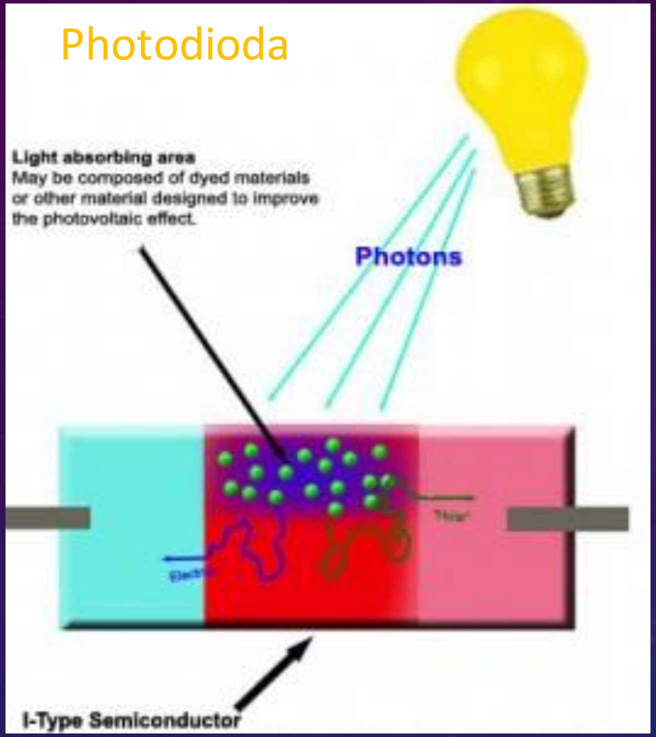
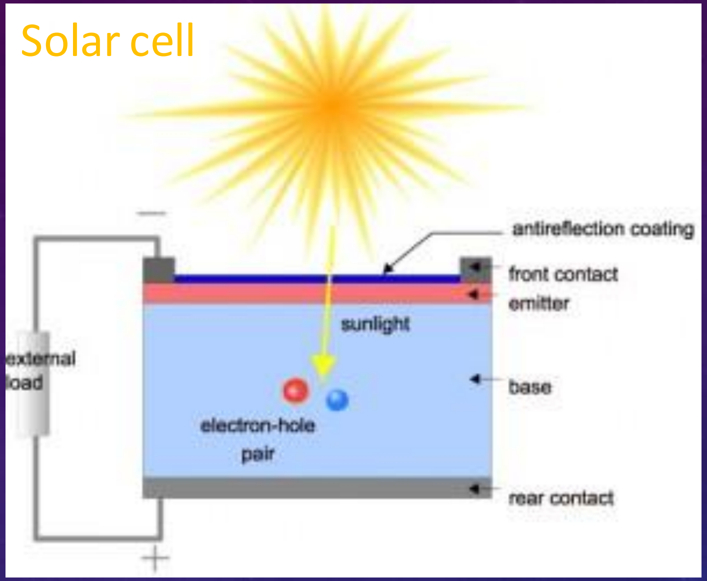
3. Green electroluminescence from an n-ZnO: Er/p-Si heterostructured light-emitting diode
   S Iwan, S Bambang, JL Zhao, ST Tan, HM Fan, L Sun, S Zhang, HH Ryu, et al
   Physica B: Condensed Matter 407 (14), 2721-2724 (2012)
4. Ultraviolet and visible electroluminescence from n-ZnO/SiOx/(n, p)-Si heterostructured light-emitting
   diodes
   ST Tan, XW Sun, JL Zhao, S Iwan, ZH Cen, TP Chen, JD Ye, GQ Lo, et al
   Applied Physics Letters 93 (1) (2008)

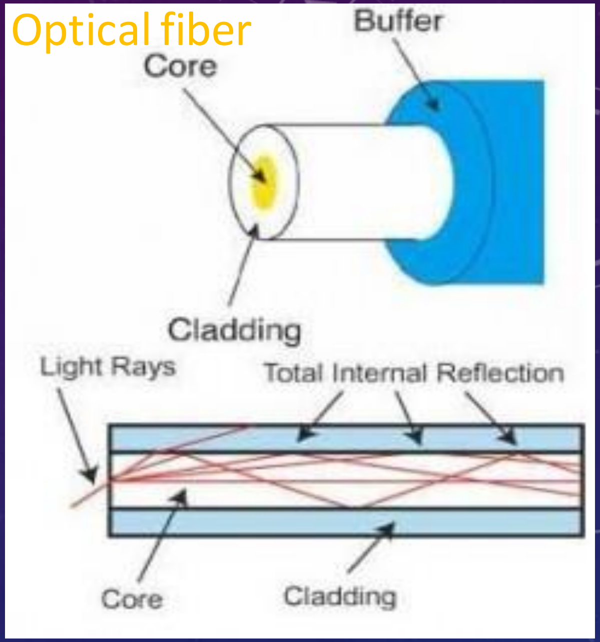
ORCID : https://orcid.org/0000-0003-3415-8466
SCOPUS : https://www.scopus.com/authid/detail.uri?authorId=24468037000
WoS : https://www.webofscience.com/wos/author/record/AFK-5687-2022
Researchgate : https://www.researchgate.net/profile/S-Iwan

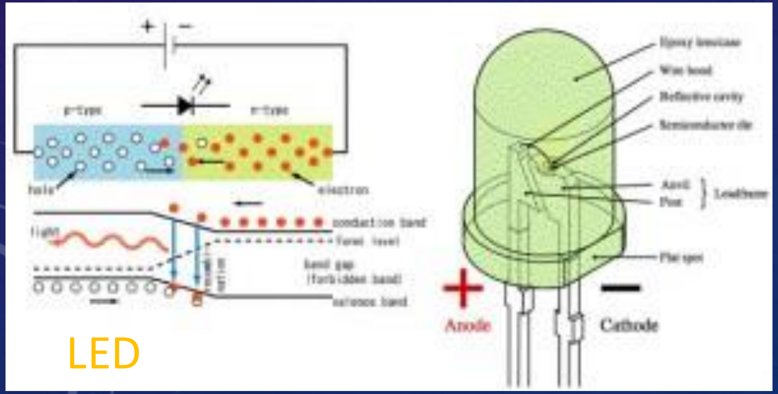
MARI BERKOLABORASI

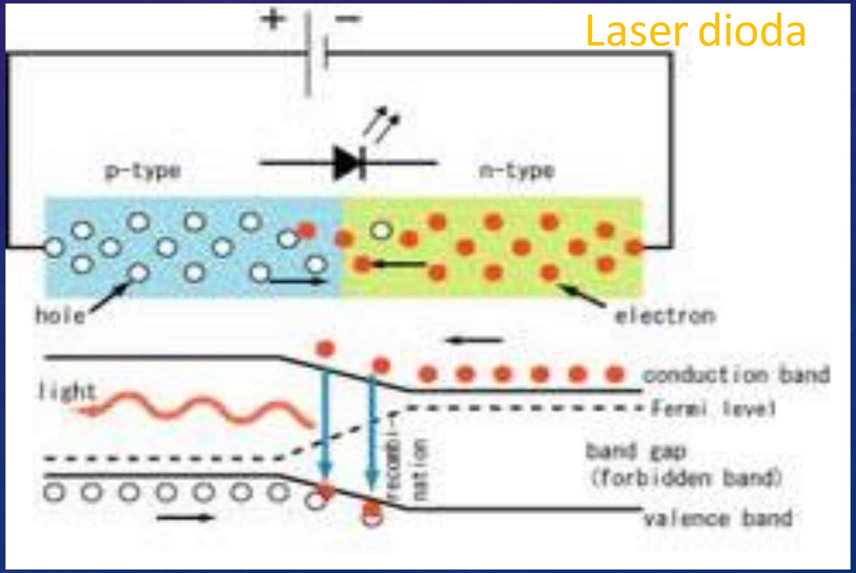
OPTOELEKTRONIKA

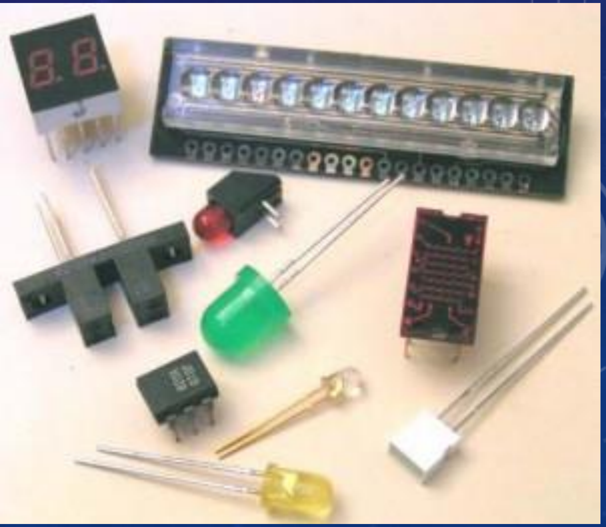




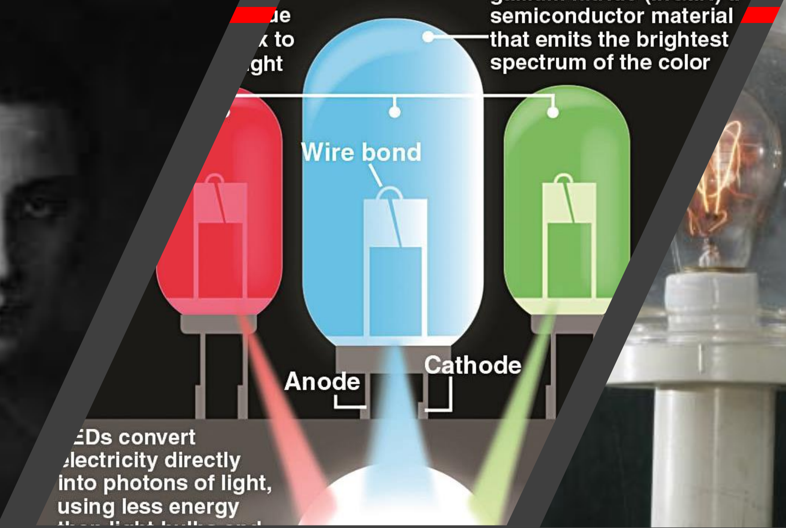


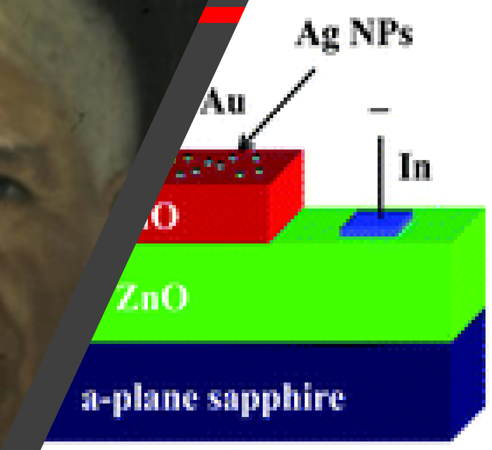


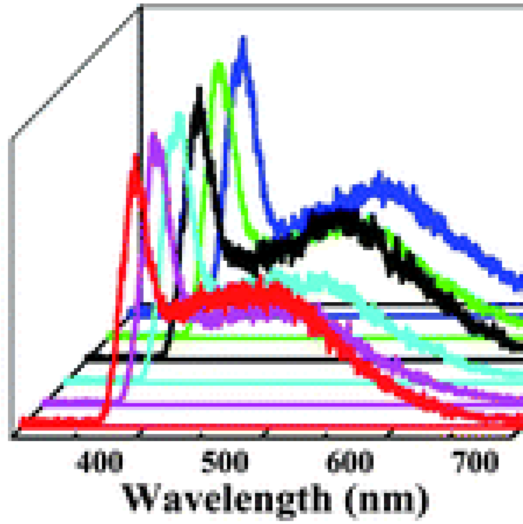




https://www.elprocus.com/optoelectronics-devices-with-their-applications/

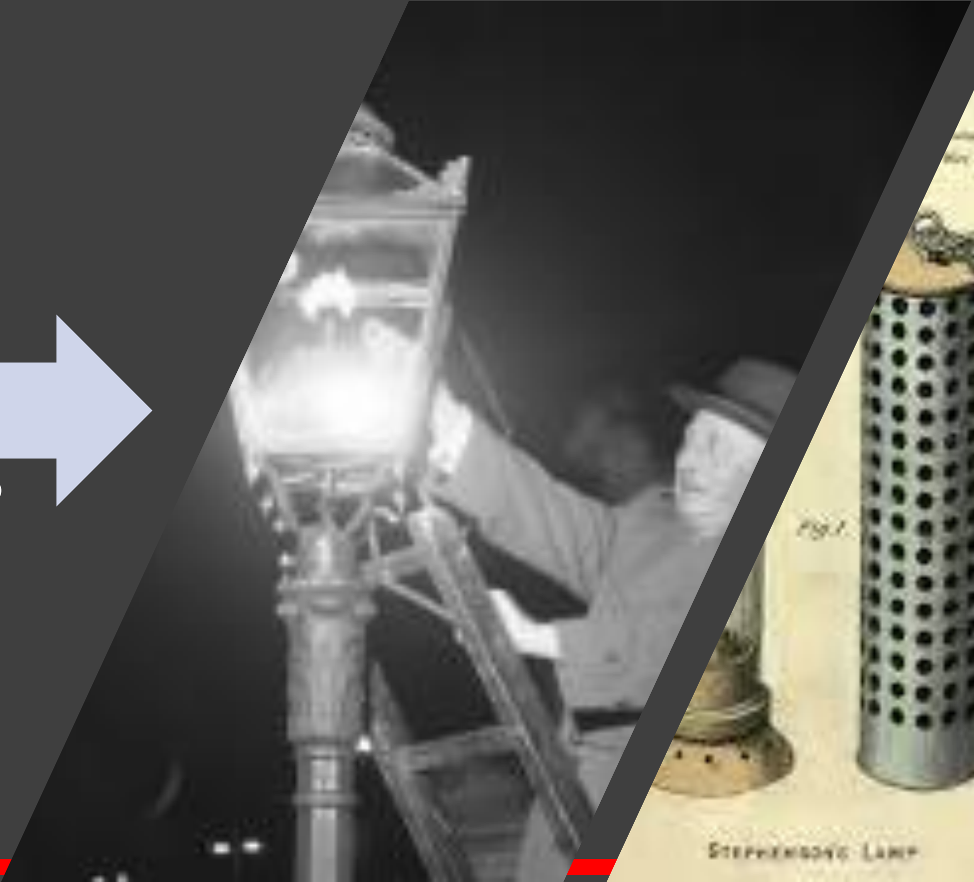


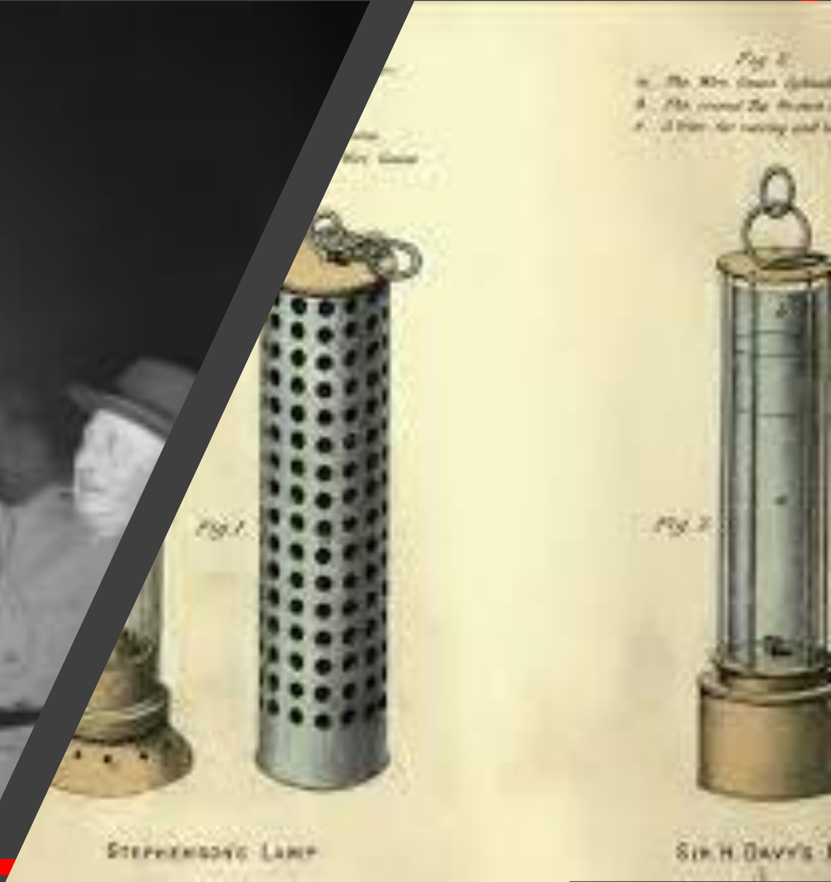




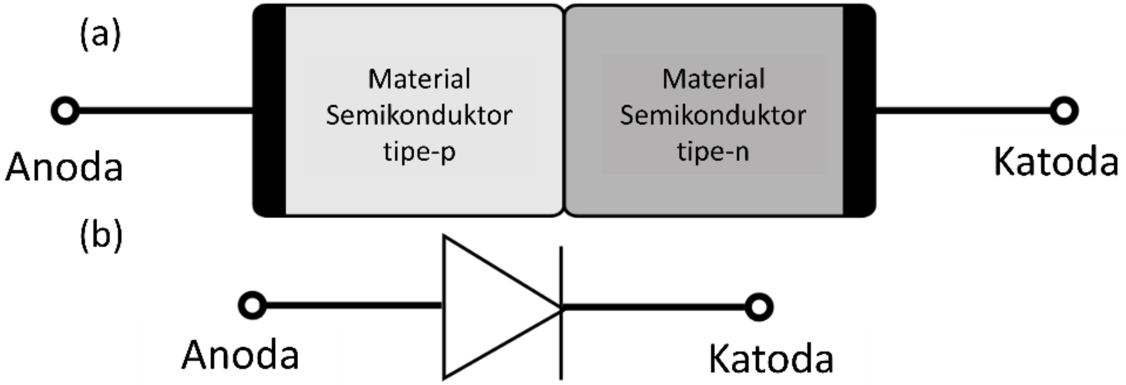
Sejarah Teknologi Sumber Cahaya

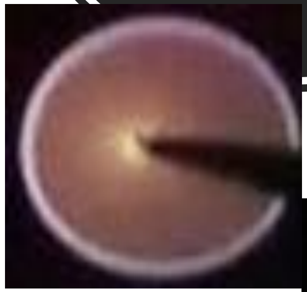
- Lampu gas--William Murdoch (1792)
- Lampu Davy--Humphry Davy (1815)
- Lampu pijar (bohlam)--Thomas Alva Edison (1879)
- LED--Oleg Vladimirovich Losev (1920)
- Blue light LED based GaN—Shuji Nakamura, Isamu Akasaki, Hiroshi Amano (1993)
- ZnO-LED ???

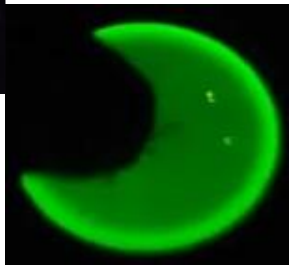




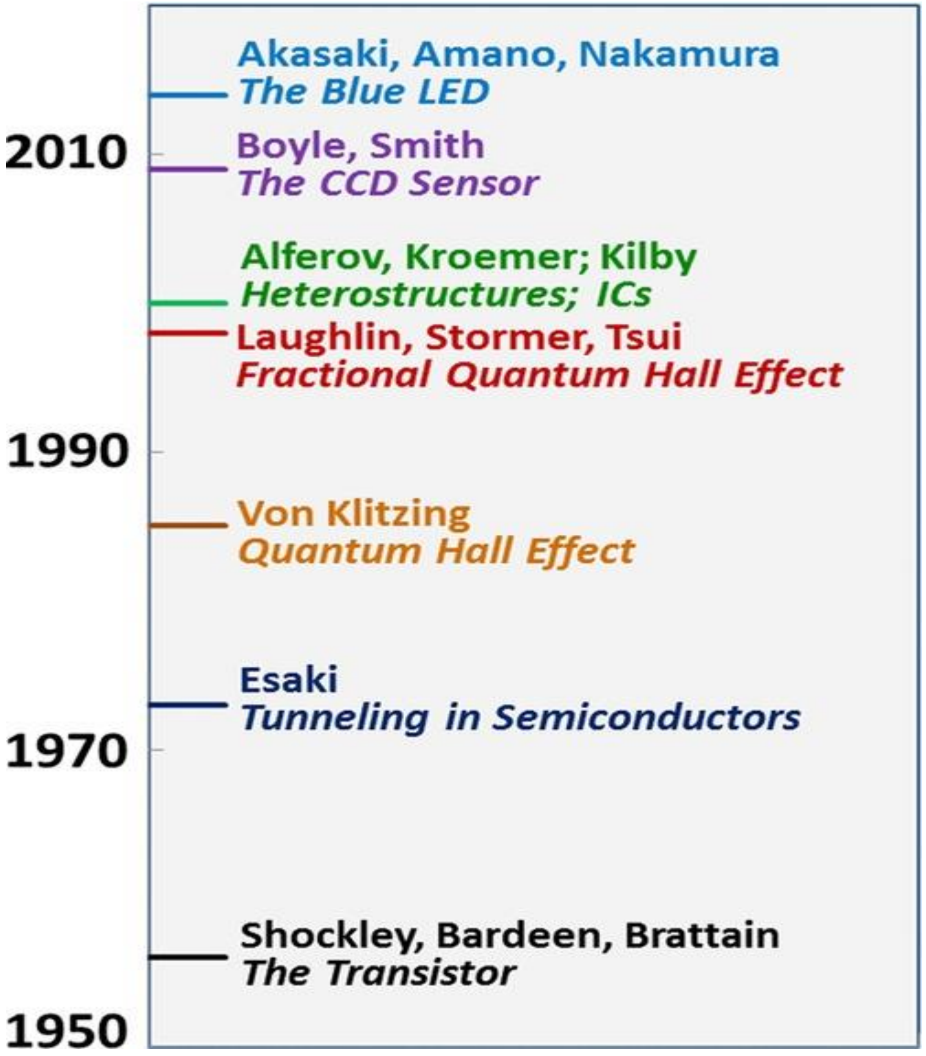
Lampu LED-Light Emitting Diode







The Blue LED Nobel Prize: Historical context



Prof. Akasaki

Born: 1929, Chiran, Japan
Meijo Univ and Nagoya Univ, Japan

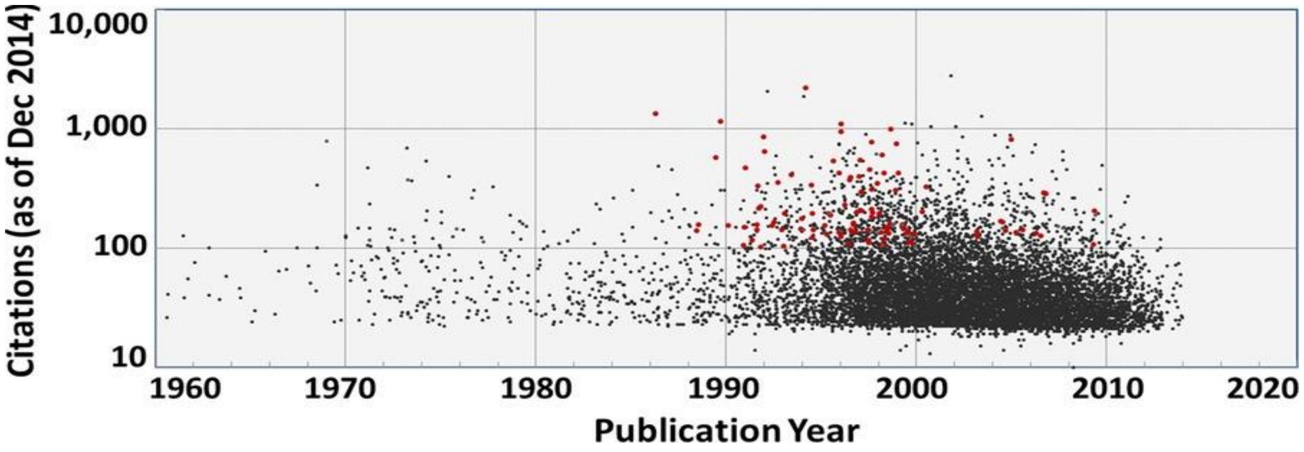
Prof. Amano

Born: 1960, Hamamatsu, Japan
Nagoya Univ, Japan

Prof. Nakamura

Born: 1954, Ikata, Japan
Univ. Of California, USA

"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"



Annalen der Physik, Volume: 527, Issue: 5-6, Pages: A53-A61, First published: 19 June 2015, DOI: (10.1002/andp.201570058)

Sumber LED Cahaya Putih

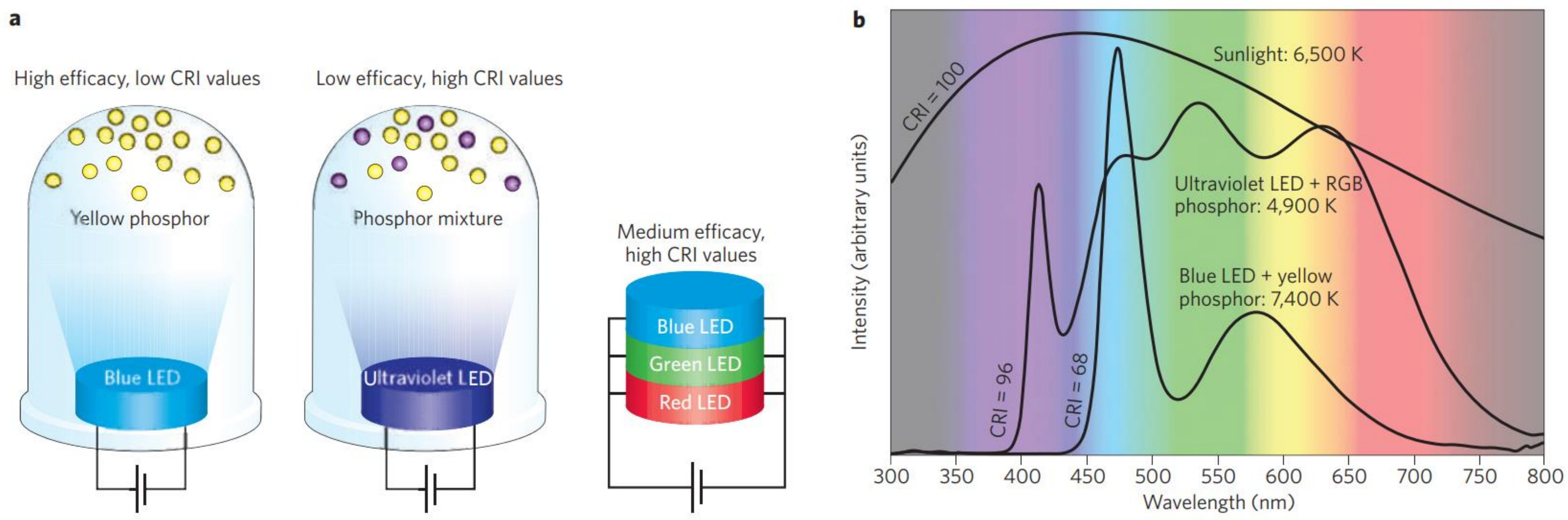


Figure 2 | White light based on LEDs. **a**, Three dominant ways to produce white light based on LEDs. **b**, Comparison of the spectrum of ideal sunlight with two LED-based white-light sources.

Pimputkar S, Speck J S, Denbaars S P and Nakamura S 2009 Prospects for LED lighting *Nat. Photonics* **3** 180–2

Cadangan Seng Indonesia (2016) dan Dunia (2018)

China memiliki produksi pertambangan seng terbesar di dunia, untuk Indonesia belum ada produksi pertambangan seng

https://www.esdm.go.id/assets/media/content/content-peluang-komoditas-timbal-dan-seng-indonesia.pdf

No	Jenis Mineral	Cadangan (Ton) Indonesia		Dunia	Perbandingan	
1	Nikel	4,500,000	**	74,000,000 **	6.08	%
2	Kobalt	484,461.33	*	7,100,000 **	6.82	%
3	Timbal	12,361,128	*	88,000,000 **	14.05	%
4	Seng	22,139,073	*	230,000,000 **	9.63	%
5	Alluminium dan Bauksit	1,000,000,000	**	30,000,000,000 **	3.33	%
6	Besi	1,823,999,935	*	253,000,000,000 **	0.72	%

Setiawan A 2022 Potensi Cadangan Mineral Dan Batubara Di Indonesia Dan Dunia *INTAN J. Penelit. Tambang* **1** 20–31

ZnO Overview

ZnO vs GaN

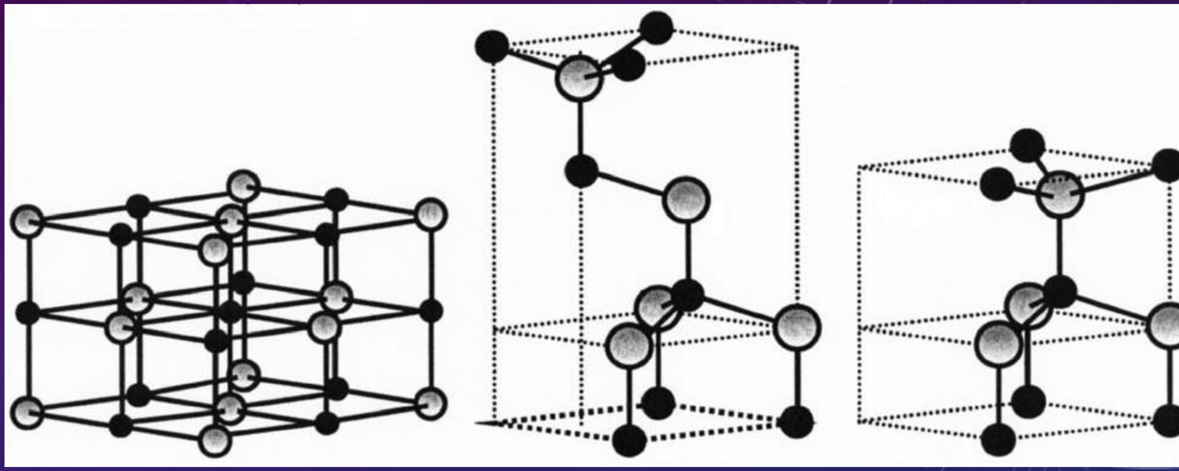
Material	Crystal structure	Lattice parameter a (Å) c (Å)	Band gap energy (eV)	Energy of cohesion (eV)	En. of fusion (K)	Excitonic binding energy (meV)	Dielectric constant ε(0) ε(∞)
ZnO	Wurtzite	3.25	3.37	1.89	2248	60	8.75
		5.21				3.75	
ZnS	Wurtzite	3.82	3.8	1.59	2103	30	9.6
		6.26				5.7	
ZnSe	Zincblende	5.66	2.7	14.29	1793	20	9.1
							6.3
GaAs	Zincblende	5.65	1.43			4.2	—
GaN	Wurtzite	3.19	3.39	2.24	1973	21	8.9
		5.19				5.35	
6H–SiC	Wurtzite	3.18	2.86	3.17	>2100	—	9.66
		15.12					6.52

J. Phys. D: Appl. Phys. 40 (2007) 6312

ZnO has three key advantages

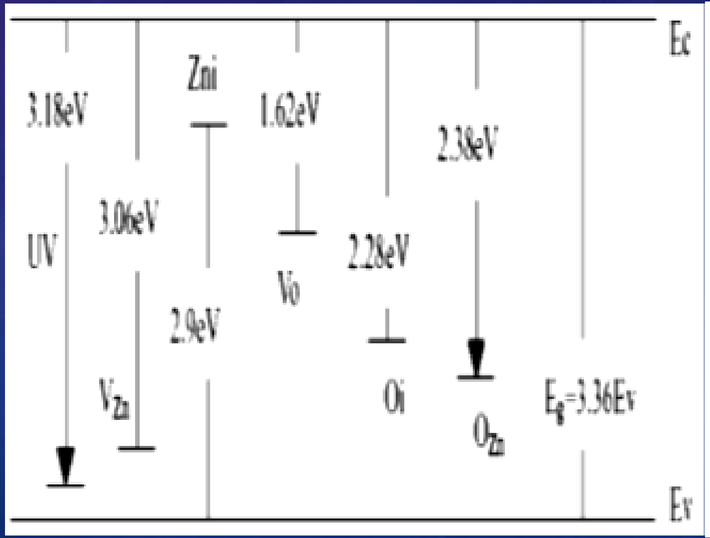
- it exhibits both semiconducting and piezoelectric (PZ) properties that can form the basis for electromechanically coupled sensors and transducers.
- relatively biosafe and biocompatible, and it can be used for biomedical applications with little toxicity.
- Exhibits the most diverse and abundant configurations of nanostructures know

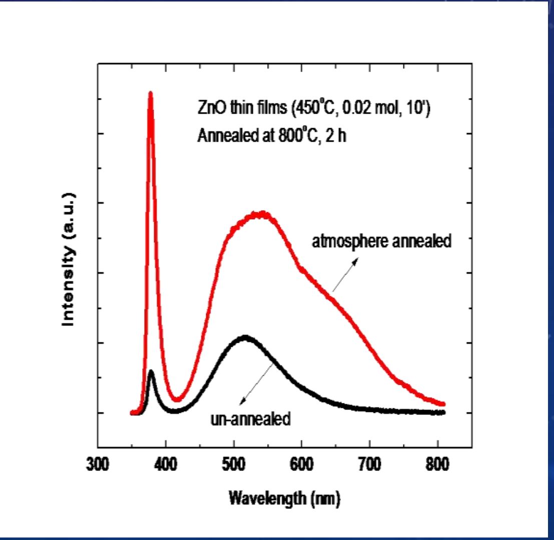
ZL Wang and J Song, Science 312, 2006



(a) cubic rocksalt, (b) cubic zinc blende, (c) hexagonal wurtzite

S.J. Pearton, D.P. Norton, K. Ip, Y.W. Heo, T. Steiner, Progress in Materials Science 50 (2005)





X.M. Fan, J.S. Lian, Z.X. Guo, H.J. Lu, Appl. Surface Science, 239, 2005

Defect in ZnO Structure

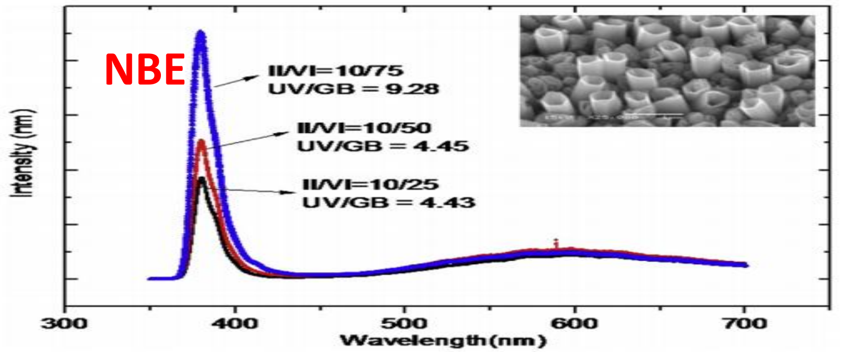
- **C.G. Van de Walle., Phys. Rev. Lett. 85 (2000)→**formation energies and electronic structure of native defects and hydrogen is common impurity
- **A.F. Kohan et al., Phys. Rev. B 61, 15019 (2000)→**theoretically, both oxygen vacancy and zinc interstitial have high formation energies in n-type ZnO
- **D.C. Look et al., Phys. Rev. Lett. 95, 225502 (2005)→** Oxygen vacancy and Zinc interstitial both are deep donor
- **X.M. Fan, J.S. Lian, Z.X. Guo, H.J. Lu, Appl. Surface Science, 239, 2005→**The intrinsic defects in ZnO thin films generally are zinc vacancy V_{Zn}, oxygen vacancy V_{O}, interstitial zinc Z_{ni}, interstitial oxygen O_{i}, and antisite oxygen O_{Zn}

Substrate	Crystal Structure	Lattice parameter a	Lattice parameter c	Lattice Mismatch (%)
ZnO	Hexagonal	3.252	5.213	0
GaN	Hexagonal	3.189	5.185	1.8
AlN	Hexagonal	3.112	4.980	4.5
Al_2O_3	Hexagonal	4.757	12.983	18
Si	Cubic	5.430		40.1

Jin Xu., Luminescence in ZnO., Master Thesis, Virginia Commonwealth University (2004).

Effect of different substrates

Intensity NBE emission increased with decreasing lattice mismatch



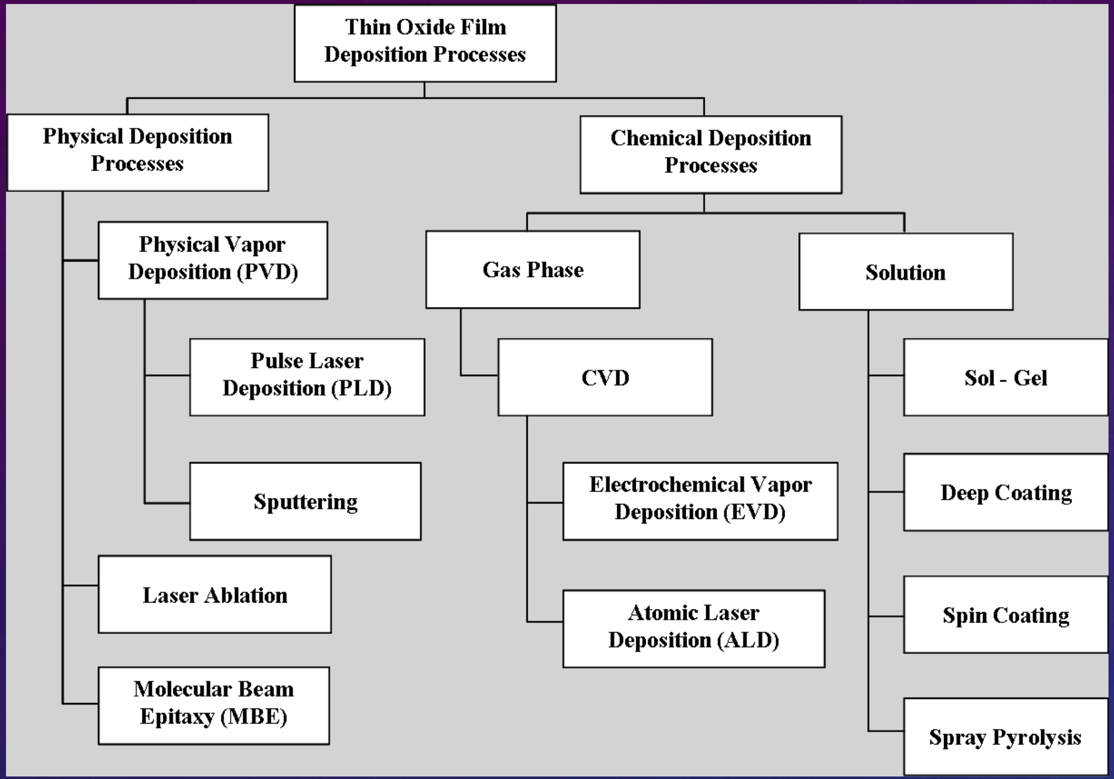
Bottleneck to produce p-n homojunction

Challenge→High efficiency devices based ZnO homostructure very difficult to be realized

EFFECTIVE APPROACH TO ADJUST THE ELECTRICAL, OPTICAL, AND MAGNETIC PROPERTIES, WHICH IS CRUCIAL FOR PRACTICAL APPLICATIONS

- **Vande Walle (*Physical Review Letter 85* , 1012-1015)**
  - *the n-type conductivity of unintentionally doped ZnO films is only due to hydrogen (H) → the assumption is valid since hydrogen is always present in all growth methods and can easily diffuse into ZnO in large amounts due to its large mobility*
- **The n-type doping of ZnO (*Journal Crystal Growth 538* , 237-239.):**
  - *group III (Al, Ga, and In) as substitutional elements for Zn and*
  - *group VII (Cl and I) as substitutional elements for O*
- **The p-type doping in ZnO (*Physics Review B 66* , 073202):**
  - *group I elements (Li, Na, and K) for Zn sites or*
  - *group V elements (N, P, and As) for O sites*

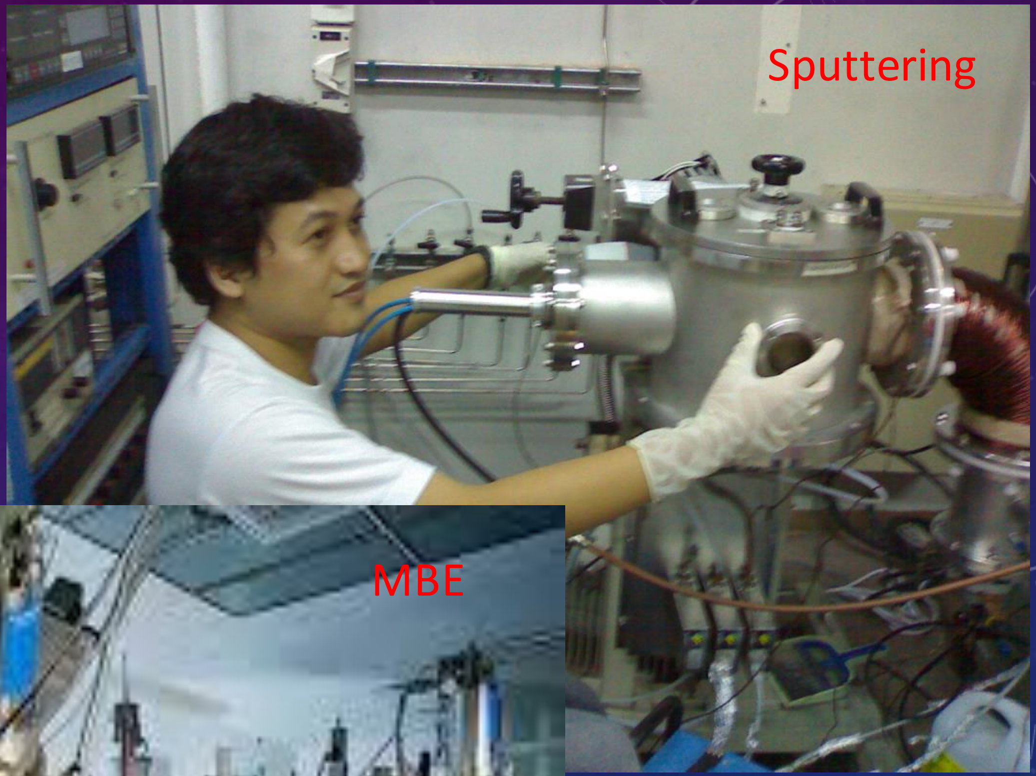
Berbagai Metode Sintesis (Studi kasus ZnO dan II-VI Semiconductor)



ZnO thin films and nanostructure on various substrate with different growth techniques

1. PLD (*X. W. Sun and H. S. Kwok, J. Appl. Phys. 86, 408-411 (1999)*)
2. MBE (*K. Nakahara et al, J. Crystal Growth 237–239 (2002)*)
3. MOCVD (*X. Li, et al, J. Vac. Sci. Technol.* ***A 21*** *(2003), S. Iwan et al, Vacuum (2018)*)
4. Sputtering (*A.V. Singh, et al, J. Appl. Phys. 93 (2003)*)
5. USP (*K. Krunk et al, Physica Scripta, 79, 209-212 (1999), S Iwan et al, Material Science and Semiconductor Processing, 2015*)


MOCVD
Veeco
TurboDisc®
SOXAL
PURIFIED


Sputtering


PVD
Kurt J. Lesker


MBE


476
33
Tubular furnace


Scanning electron microscopy


XRD

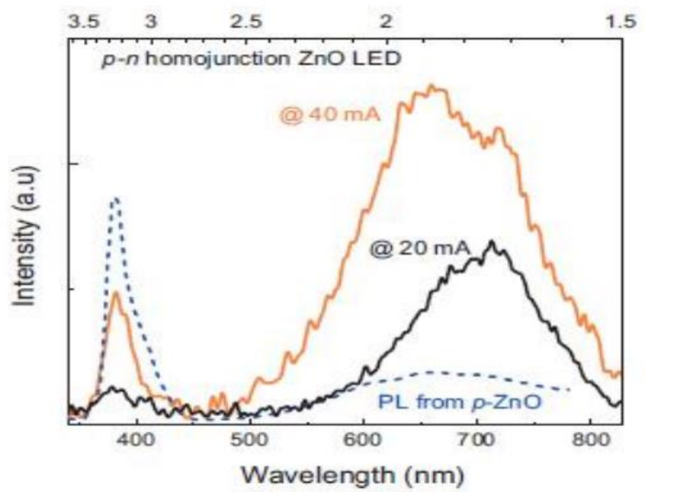

TEM


X-ray photoelectron spectroscopy

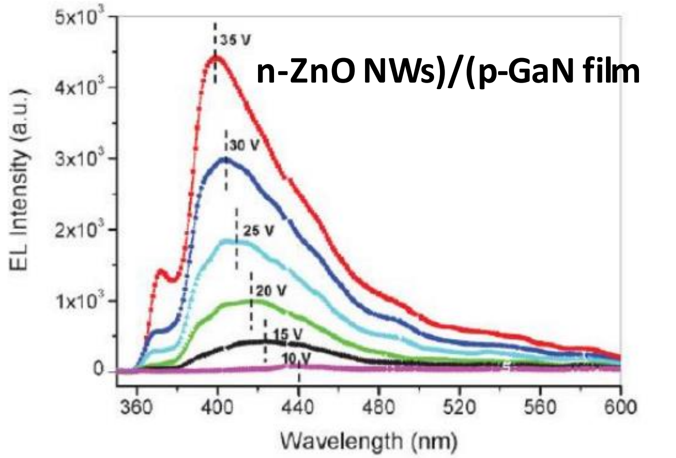

PL laboratory

LED BASED ZNO

Growth technique	Structure	Light emission (nm)
MBE	p-ZnO:N/i-ZnO/n-ZnO	Violet-green
	p-ZnO:N/n-ZnO	420
	p-ZnO:Sb/n-ZnO:Ga	383.3, 490, 605
	p-ZnO:Sb/n-ZnO:Ga	385-393
MOCVD	p-ZnO:N/n-ZnO/ZnO bulk	372, 435, 520
	n-ZnO/p-ZnO:As/GaAs	388, 496
	n-ZnO:Ga/p-ZnO:N	388, 516
Ion implantation	p-ZnO:N/n-ZnO bulk	530, 740
	p-ZnO:As nanorod /n-ZnO nanorod	380, 630
	p-ZnO:P nanorod /n-ZnO nanorod	UV, 510, 800
Magnetron sputtering	p-ZnO:P /n-ZnO	380, 640
Solution method	p-ZnO:P nanorod / n-ZnO film	415, 450-650
Hybrid beam deposition	p-ZnO:As /p-$Be_{0.3}Zn_{0.7}O$ /(ZnO/$Be_{0.2}Zn_{0.8}O$)MQW/ n-$Be_{0.3}Zn_{0.7}O$/n-ZnO	363, 388, 550,



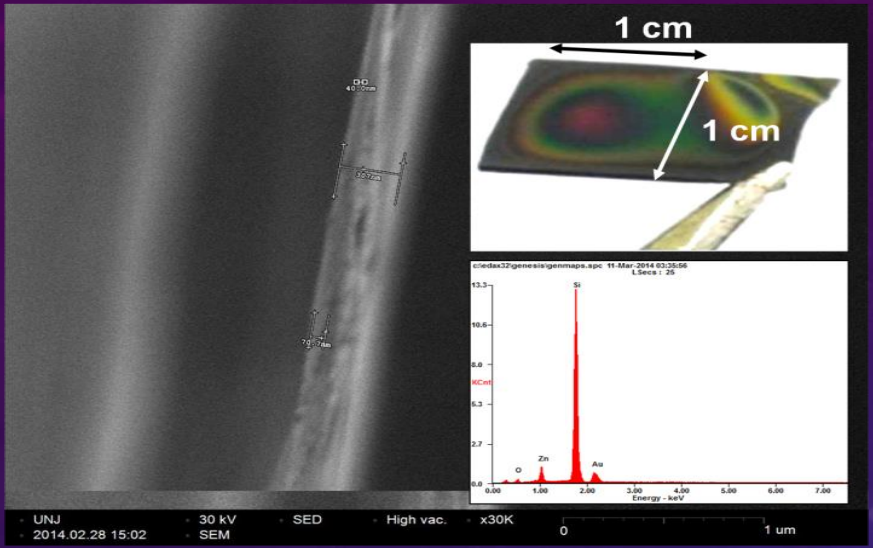
Lim J H et al. Adv.Mater.2006; 18, 2720–2724

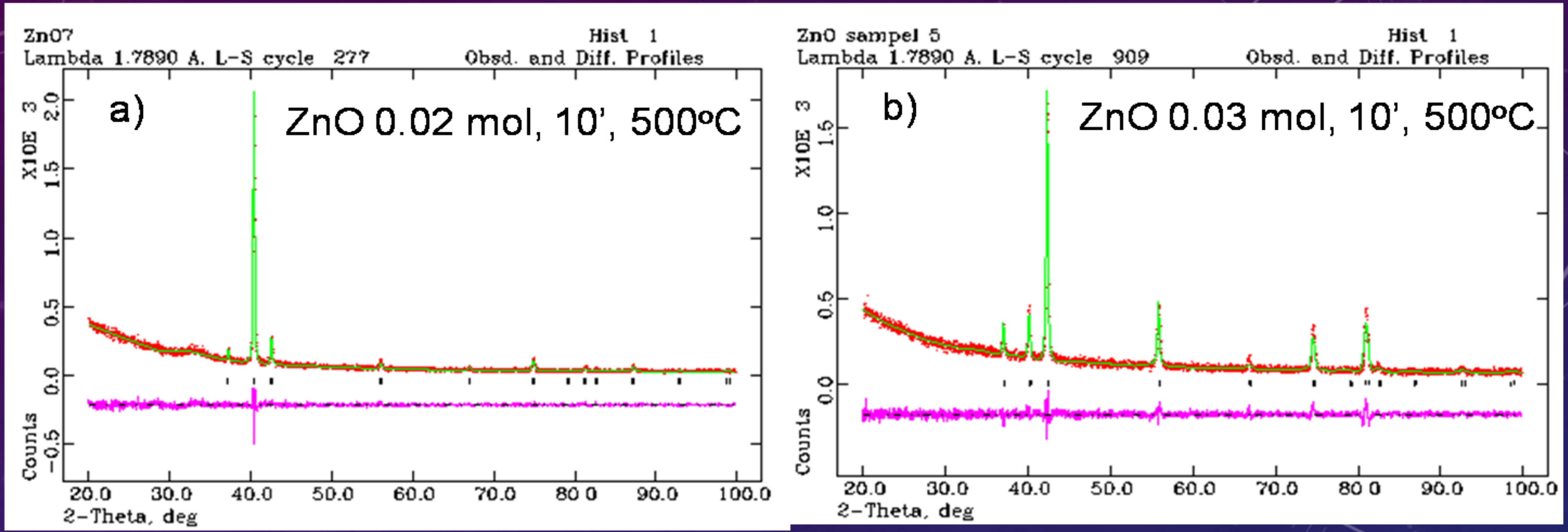


Zhang X M et al. Adv.Mater.2009; 21, 2767-2770

Growth technique	Structure	Light emission (nm)
MBE	n-ZnO/p-GaN	570
	n-ZnO/p-GaN	450, 520
	n-ZnO:Ga/p-GaN:Mg	430
	n-MgZnO/CdZnO/p-GaN	390, 410
	n-MgZnO/n-ZnO/p-AlGaN/p-GaN	390
Magnetron sputtering	n-ZnO:Ga/p-GaN:Mg	430, 440, 480
	n-ZnO /p-GaN	400, 400-700
	n-ZnO:Ga/i-ZnO/p-GaN:Mg	405, 530, 620
	n-ZnO/AlN/p-GaN:Mg	392
	n-ZnO:Er/p-GaN:Mg	537, 538
PLD	p-$SrCu_2O_2$/n-ZnO	382
	n-ZnO/p-GaN:Mg	375
	n-ZnO/p-GaN:Mg	365.4, 384
MOCVD	n-ZnO /p-Si	580
	n-ZnO /p-Si	400-600
CVD	n-ZnO/p-AlGaN	389
	n-ZnO/p-GaN	430
HWEP sputternng	p-$CuGaS_2$/n-ZnO:Al	496-775

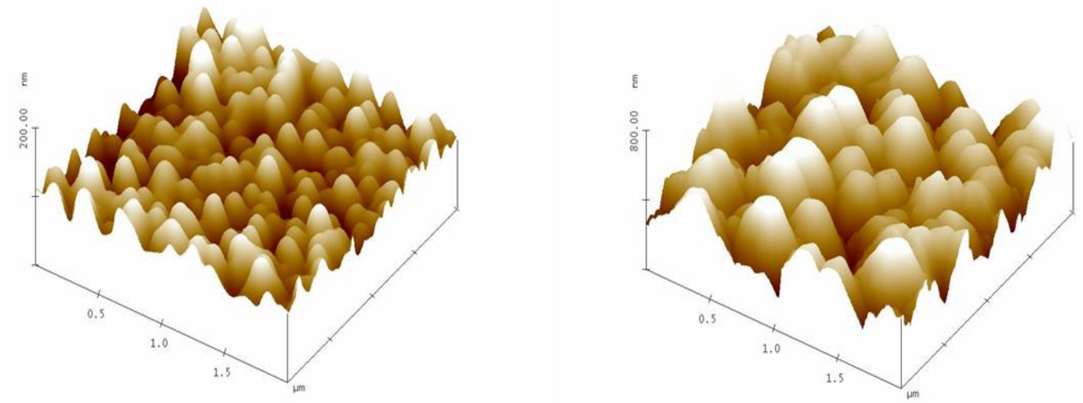
ZnO Thin Films





According to Rietveld refinement, the GSAS calculation has goodness fit with observed curve

Annealed 800°C for 2 h



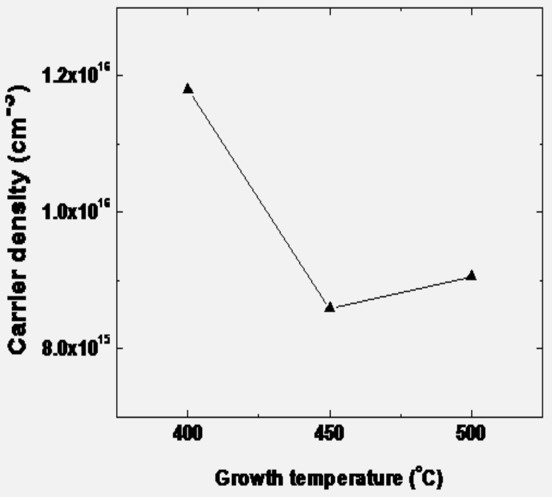
RMS roughness 36.543

(a)

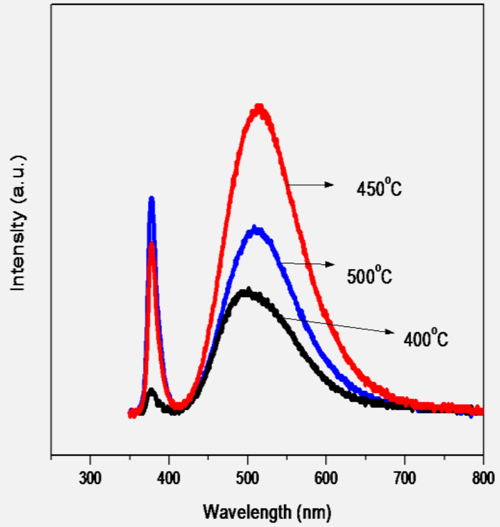
RMS roughness 24.754

(b)

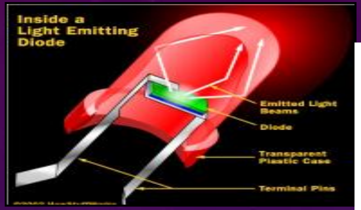
By annealing treatment at 800°C, the Zn and O incorporates on to lattice sites

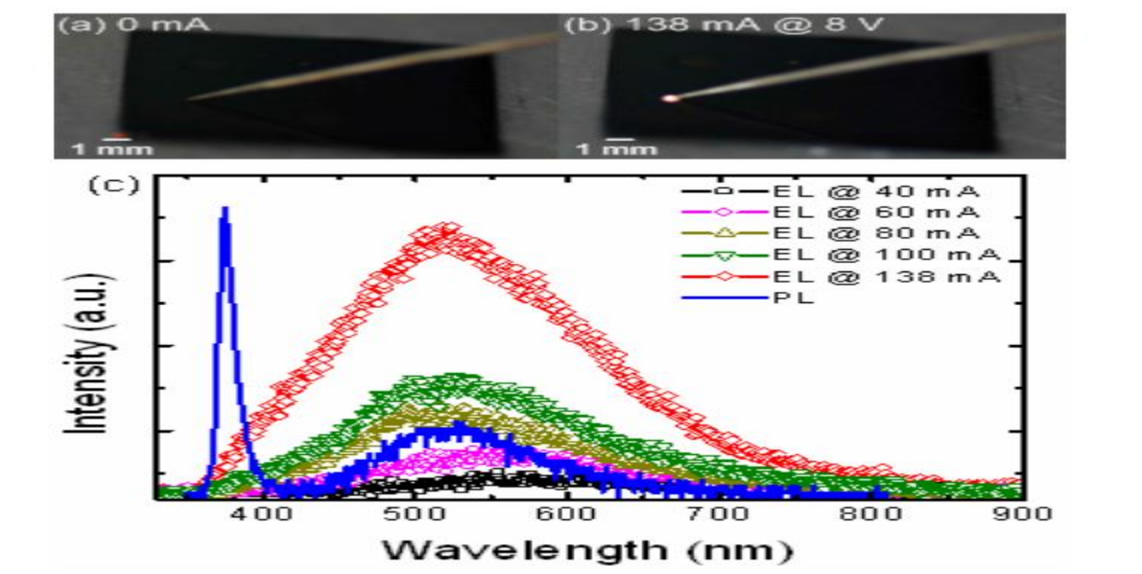


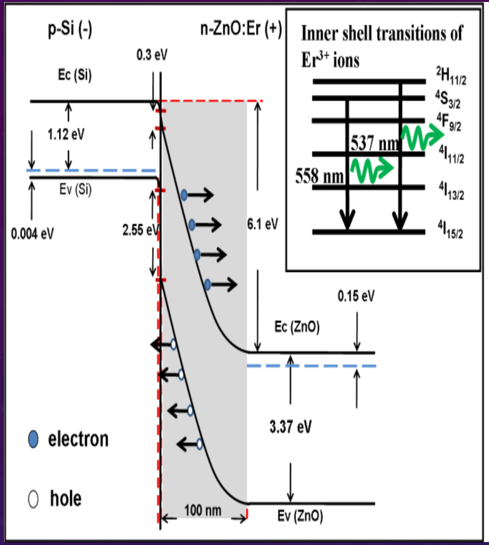
(c)

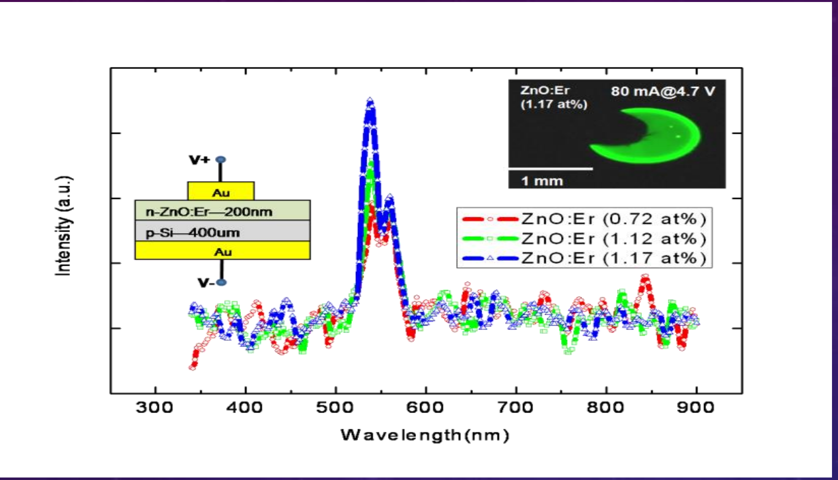


LED-ZnO Heterostructure

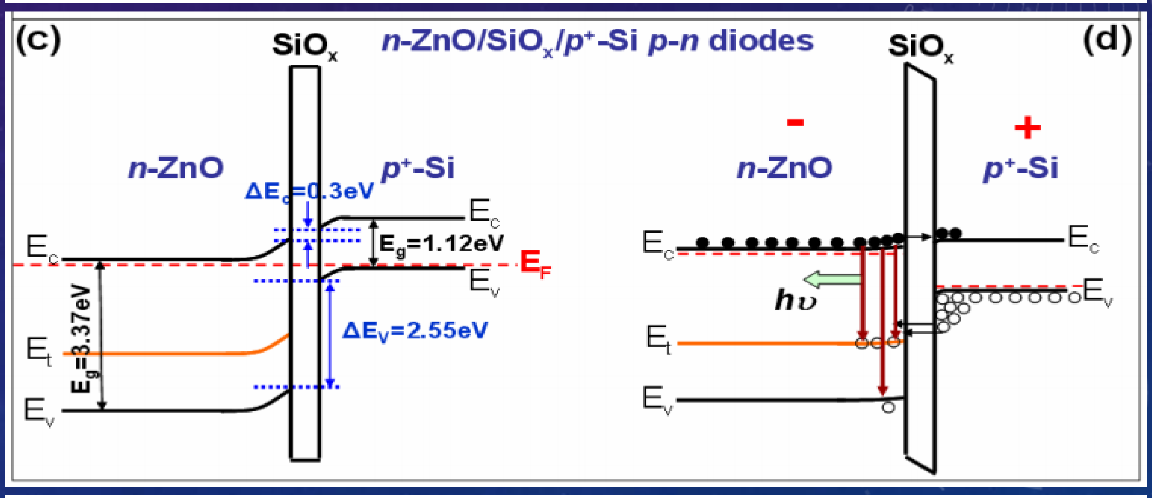




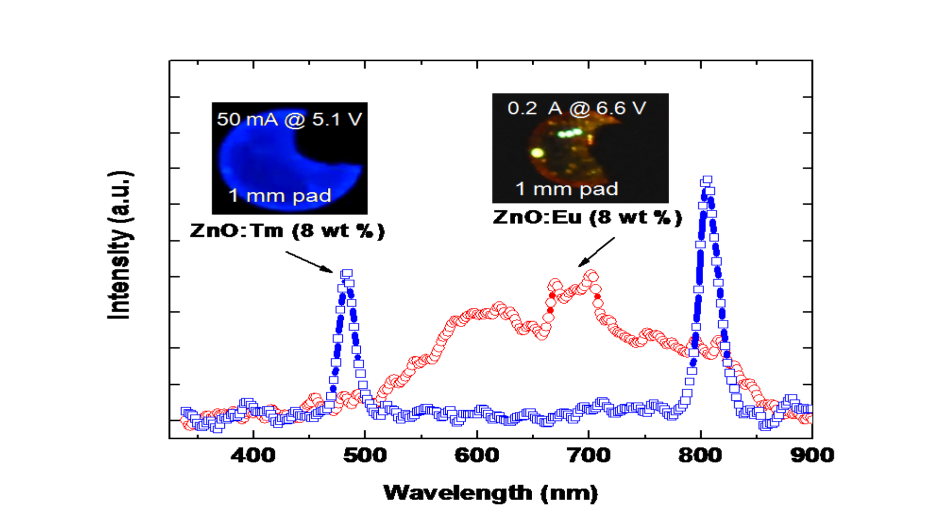


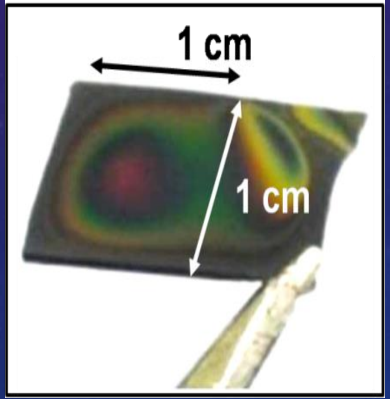


S Iwan, et. Al. Physica B: Condensed Matter 407 (14), 2721-2724, 2012



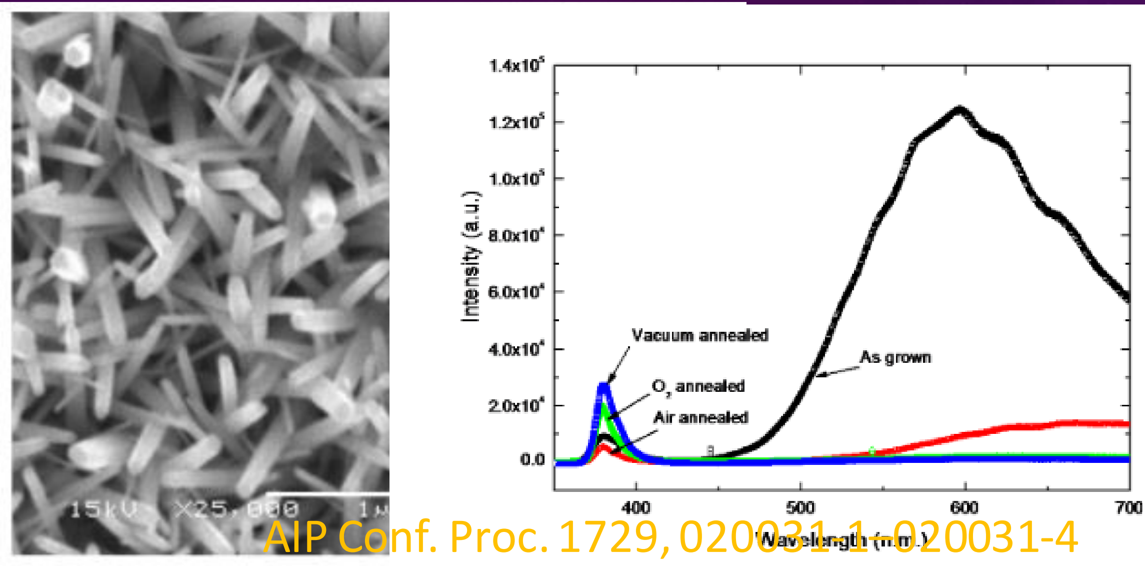
ST. Tan, S. Iwan et al, Applied Physics Letter 93, 013506 (2008)



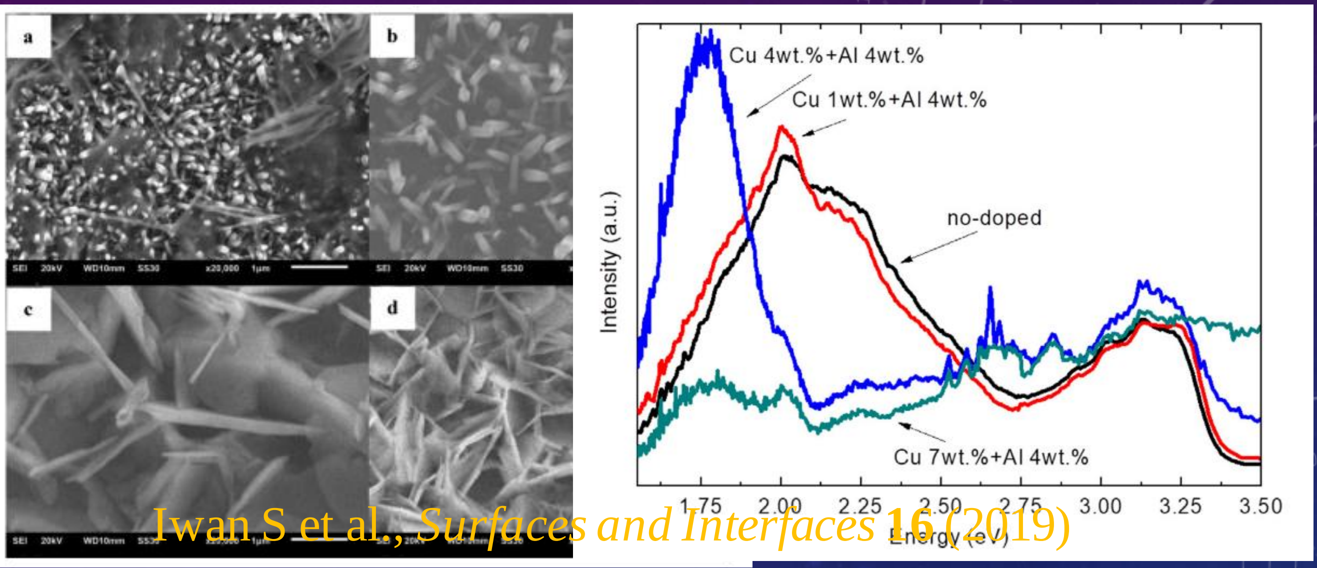


S. Iwan, et. al, Material Science in Semiconductor Processing 30, 263-266, 2015

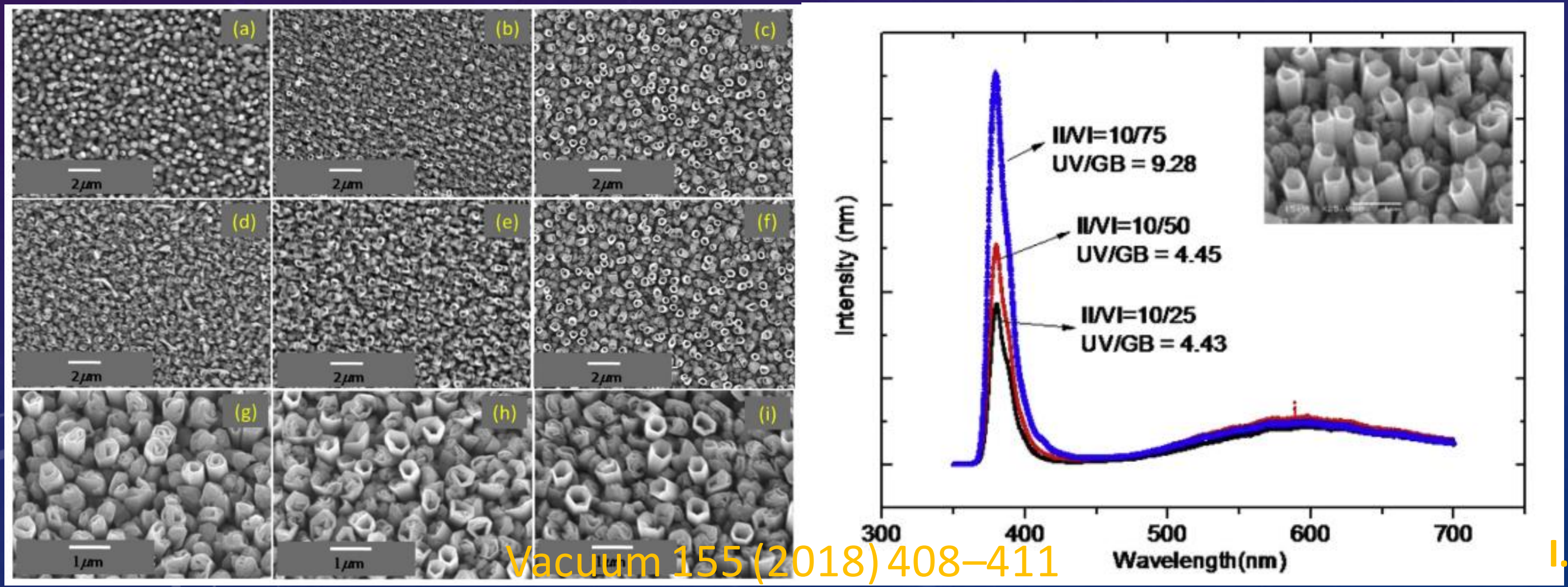
OPTICAL PROPERTIES-PHOTOLUMINESCENCE (ZNO NANORODS)



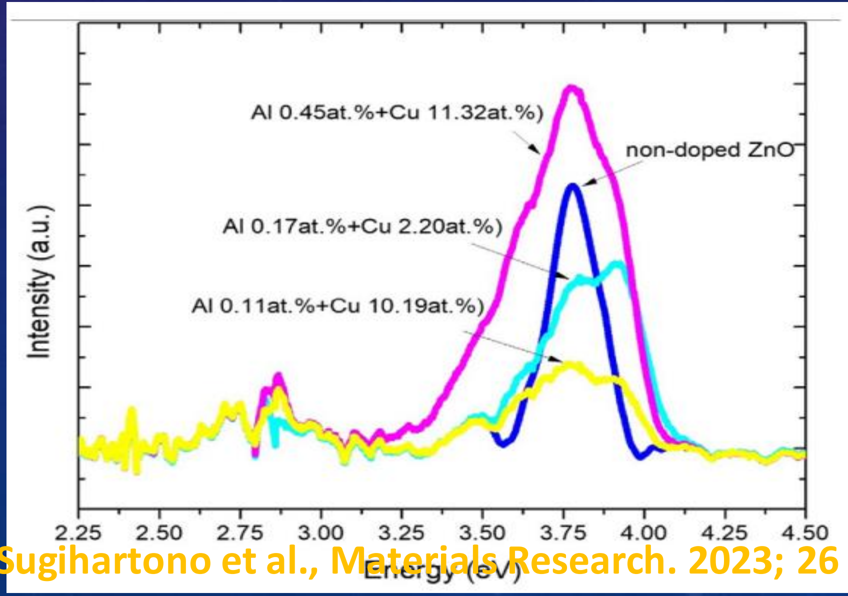
AIP Conf. Proc. 1729, 020031-1–020031-4



Iwan S et al., *Surfaces and Interfaces* **16** (2019)



Vacuum 155 (2018) 408–411



I. Sugihartono et al., Materials Research. 2023; 26

KESIMPULAN

- ZnO memiliki potensi untuk menggantikan GaN sebagai material semikonduktor dalam aplikasi optoelektronika khususnya LED
- ZnO berbasis homojunction masih memiliki efisiensi yang rendah, factor utama adalah menghasilkan tipe-p ZnO masih sukar direalisasikan. Terdapat tiga factor utama:
  - Solubilitas doping (golongan I dan V) rendah
  - Energi ionisasi akseptor sangat kuat
  - Mekanisme kompensasi dopan akseptor oleh defects

Terima Kasih

Berkreasi sekecil apapun akan menjadi pelita ditengah keterbatasan

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