

In

49

114.82



Indium

# Indium

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CHEM-E4130

**A!** Aalto University  
School of Chemical  
Engineering

# Contents

- Indium in the Periodic Table
- Element – history, abundance, production, price
- Chemistry – chemical and other properties
- Compounds
- Exciting applications
  - Indium Nitride for Lithium-Sulfur Batteries
  - Flexible sensors from ITO
  - InZnO as semiconductor

# Indium in the Periodic Table

PubChem

1	1.0080 <b>H</b> Hydrogen Nonmetal	2											18	4.00260 <b>He</b> Helium Noble Gas																													
3	7.0 <b>Li</b> Lithium Alkali Metal	4	9.012183 <b>Be</b> Beryllium Alkaline Earth Me...	Atomic Number 17 35.45 Atomic Mass, u										5	10.81 <b>B</b> Boron Metalloid	6	12.011 <b>C</b> Carbon Nonmetal	7	14.007 <b>N</b> Nitrogen Nonmetal	8	15.999 <b>O</b> Oxygen Nonmetal	9	18.9984... <b>F</b> Fluorine Halogen	10	20.180 <b>Ne</b> Neon Noble Gas																		
11	22.989... <b>Na</b> Sodium Alkali Metal	12	24.305 <b>Mg</b> Magnesium Alkaline Earth Me...	Name Cl Chlorine Halogen Chemical Group Block										13	26.981... <b>Al</b> Aluminum Post-Transition M...	14	28.085 <b>Si</b> Silicon Metalloid	15	30.973... <b>P</b> Phosphorus Nonmetal	16	32.07 <b>S</b> Sulfur Nonmetal	17	35.45 <b>Cl</b> Chlorine Halogen	18	39.9 <b>Ar</b> Argon Noble Gas																		
19	39.0983 <b>K</b> Potassium Alkali Metal	20	40.08 <b>Ca</b> Calcium Alkaline Earth Me...	21	44.95591 <b>Sc</b> Scandium Transition Metal	22	47.867 <b>Ti</b> Titanium Transition Metal	23	50.9415 <b>V</b> Vanadium Transition Metal	24	51.996 <b>Cr</b> Chromium Transition Metal	25	54.93804 <b>Mn</b> Manganese Transition Metal	26	55.84 <b>Fe</b> Iron Transition Metal	27	58.93319 <b>Co</b> Cobalt Transition Metal	28	58.693 <b>Ni</b> Nickel Transition Metal	29	63.55 <b>Cu</b> Copper Transition Metal	30	65.4 <b>Zn</b> Zinc Transition Metal	31	69.723 <b>Ga</b> Gallium Post-Transition M...	32	72.63 <b>Ge</b> Germanium Metalloid	33	74.92159 <b>As</b> Arsenic Metalloid	34	78.97 <b>Se</b> Selenium Nonmetal	35	79.90 <b>Br</b> Bromine Halogen	36	83.80 <b>Kr</b> Krypton Noble Gas								
37	85.468 <b>Rb</b> Rubidium Alkali Metal	38	87.62 <b>Sr</b> Strontium Alkaline Earth Me...	39	88.90584 <b>Y</b> Yttrium Transition Metal	40	91.22 <b>Zr</b> Zirconium Transition Metal	41	92.90637 <b>Nb</b> Niobium Transition Metal	42	95.95 <b>Mo</b> Molybdenum Transition Metal	43	96.90636 <b>Tc</b> Technetium Transition Metal	44	101.1 <b>Ru</b> Ruthenium Transition Metal	45	102.9055 <b>Rh</b> Rhodium Transition Metal	46	106.42 <b>Pd</b> Palladium Transition Metal	47	107.868 <b>Ag</b> Silver Transition Metal	48	112.4 <b>Cd</b> Cadmium Transition Metal	49	114.818 <b>In</b> Indium Post-Transition M...	50	118.71 <b>Sn</b> Tin Post-Transition M...	51	121.760 <b>Sb</b> Antimony Metalloid	52	127.6 <b>Te</b> Tellurium Metalloid	53	126.9045 <b>I</b> Iodine Halogen	54	131.29 <b>Xe</b> Xenon Noble Gas								
55	132.90... <b>Cs</b> Cesium Alkali Metal	56	137.33 <b>Ba</b> Barium Alkaline Earth Me...											72	178.49 <b>Hf</b> Hafnium Transition Metal	73	180.9479 <b>Ta</b> Tantalum Transition Metal	74	183.84 <b>W</b> Tungsten Transition Metal	75	186.207 <b>Re</b> Rhenium Transition Metal	76	190.2 <b>Os</b> Osmium Transition Metal	77	192.22 <b>Ir</b> Iridium Transition Metal	78	195.08 <b>Pt</b> Platinum Transition Metal	79	196.96... <b>Au</b> Gold Transition Metal	80	200.59 <b>Hg</b> Mercury Transition Metal	81	204.383 <b>Tl</b> Thallium Post-Transition M...	82	207 <b>Pb</b> Lead Post-Transition M...	83	208.98... <b>Bi</b> Bismuth Post-Transition M...	84	208.98... <b>Po</b> Polonium Metalloid	85	209.98... <b>At</b> Astatine Halogen	86	222.01... <b>Rn</b> Radon Noble Gas
87	223.01... <b>Fr</b> Francium Alkali Metal	88	226.02... <b>Ra</b> Radium Alkaline Earth Me...											104	267.1... <b>Rf</b> Rutherfordium Transition Metal	105	268.1... <b>Db</b> Dubnium Transition Metal	106	269.1... <b>Sg</b> Seaborgium Transition Metal	107	270.1... <b>Bh</b> Bohrium Transition Metal	108	269.1... <b>Hs</b> Hassium Transition Metal	109	277.1... <b>Mt</b> Meitnerium Transition Metal	110	282.1... <b>Ds</b> Darmstadtium Transition Metal	111	282.1... <b>Rg</b> Roentgenium Transition Metal	112	286.1... <b>Cn</b> Copernicium Transition Metal	113	286.1... <b>Nh</b> Nihonium Post-Transition M...	114	290.1... <b>Fl</b> Flerovium Post-Transition M...	115	290.1... <b>Mc</b> Moscovium Post-Transition M...	116	293.2... <b>Lv</b> Livermorium Post-Transition M...	117	294.2... <b>Ts</b> Tennessine Halogen	118	295.2... <b>Og</b> Oganesson Noble Gas
				57	138.9055 <b>La</b> Lanthanum Lanthanide	58	140.116 <b>Ce</b> Cerium Lanthanide	59	140.90... <b>Pr</b> Praseodymium Lanthanide	60	144.24 <b>Nd</b> Neodymium Lanthanide	61	144.91... <b>Pm</b> Promethium Lanthanide	62	150.4 <b>Sm</b> Samarium Lanthanide	63	151.964 <b>Eu</b> Europium Lanthanide	64	157.2 <b>Gd</b> Gadolinium Lanthanide	65	158.92... <b>Tb</b> Terbium Lanthanide	66	162.500 <b>Dy</b> Dysprosium Lanthanide	67	164.93... <b>Ho</b> Holmium Lanthanide	68	167.26 <b>Er</b> Erbium Lanthanide	69	168.93... <b>Tm</b> Thulium Lanthanide	70	173.05 <b>Yb</b> Ytterbium Lanthanide	71	174.9668 <b>Lu</b> Lutetium Lanthanide										
				89	227.02... <b>Ac</b> Actinium Actinide	90	232.038 <b>Th</b> Thorium Actinide	91	231.03... <b>Pa</b> Protactinium Actinide	92	238.0289 <b>U</b> Uranium Actinide	93	237.04... <b>Np</b> Neptunium Actinide	94	244.06... <b>Pu</b> Plutonium Actinide	95	243.06... <b>Am</b> Americium Actinide	96	247.07... <b>Cm</b> Curium Actinide	97	247.07... <b>Bk</b> Berkelium Actinide	98	251.07... <b>Cf</b> Californium Actinide	99	252.0830 <b>Es</b> Einsteinium Actinide	100	257.0... <b>Fm</b> Fermium Actinide	101	258.0... <b>Md</b> Mendelevium Actinide	102	259.1... <b>No</b> Nobelium Actinide	103	266.1... <b>Lr</b> Lawrencium Actinide										

# Element

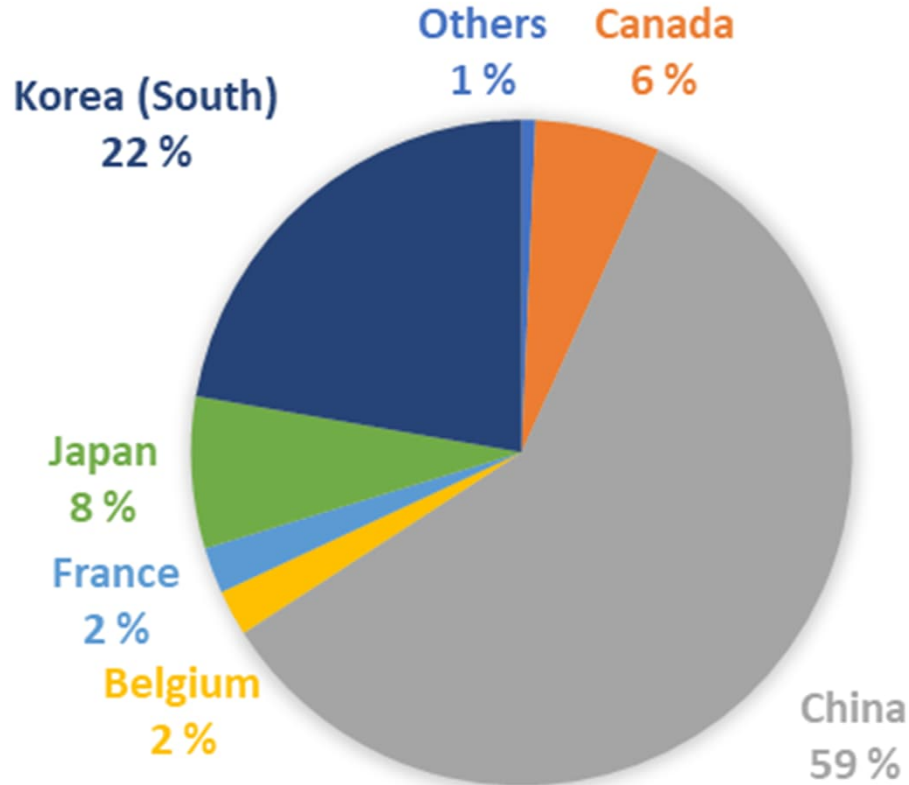
Ferdinand Reich &  
Hieronymus Richter  
1863

Indigo



[4]

## IN PRODUCTION 2022



[3]

B	10 ppm
Al	82300 ppm
Ga	19 ppm
Tl	0.8 ppm

Rare  
0.2 ppm

Production 900 tons  
per annum

# Indium price

Sn	24 USD/kg
Ga	261 USD/kg
Zn	2.6 USD/kg

~280 USD

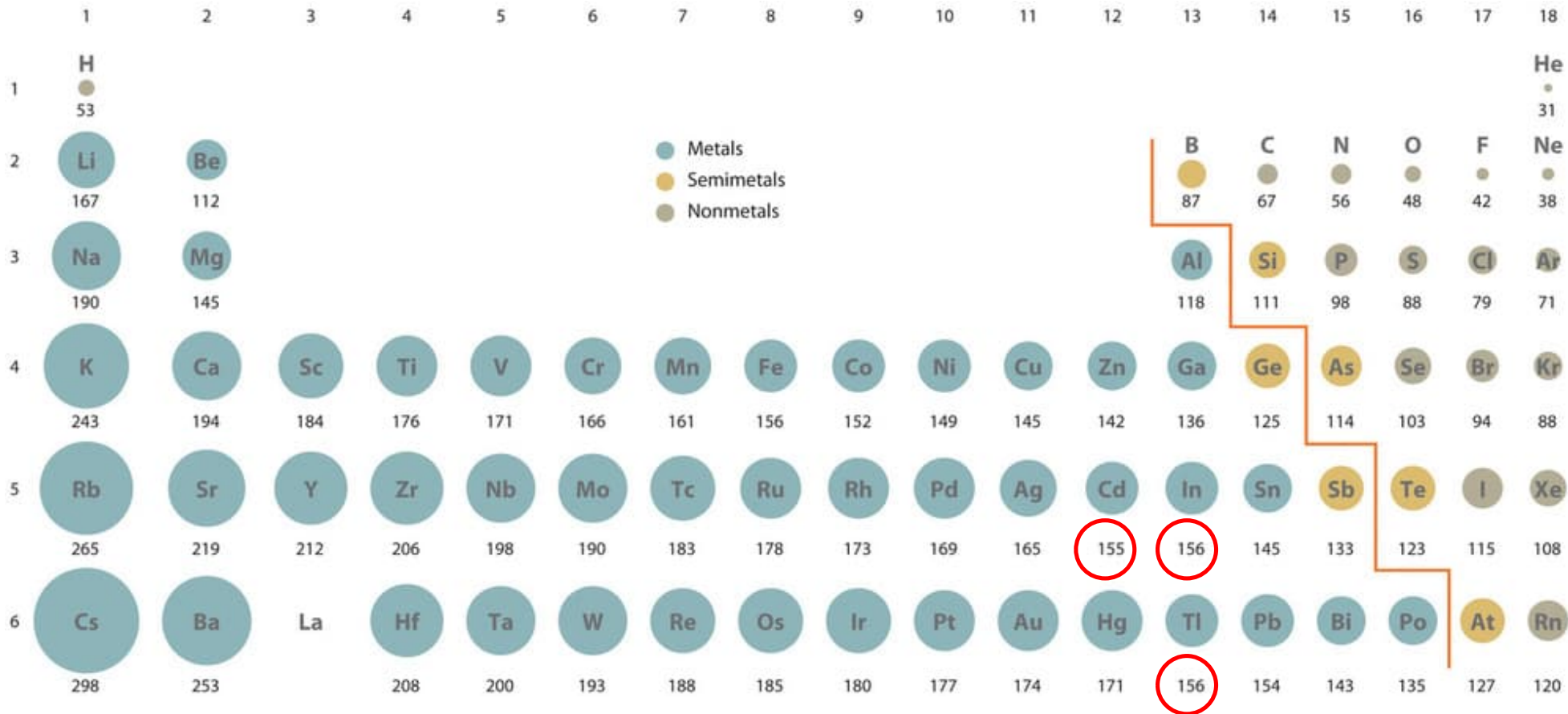


Graph source: [Indium - 2023 Data - 2017-2022 Historical - 2024 Forecast - Price - Quote - Chart \(tradingeconomics.com\)](https://tradingeconomics.com)





# Atomic radius



# Properties

## Physical properties

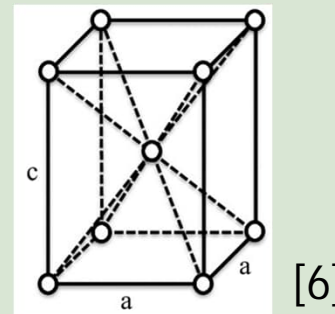
- Melting point 156.60 °C
- Boiling point 2027 °C
- Density 7.31 g/cm<sup>3</sup>

## Isotopes

- One stable isotope <sup>113</sup>In
- 38 unstable isotopes
- Natural indium:  
95.72 % <sup>113</sup>In  
4.28 % <sup>115</sup>In

## Structure

- Crystal structure: Body-centered tetragonal



- Wets glass and other surfaces like gallium
- When bended emits a high-pitched 'cry' like tin



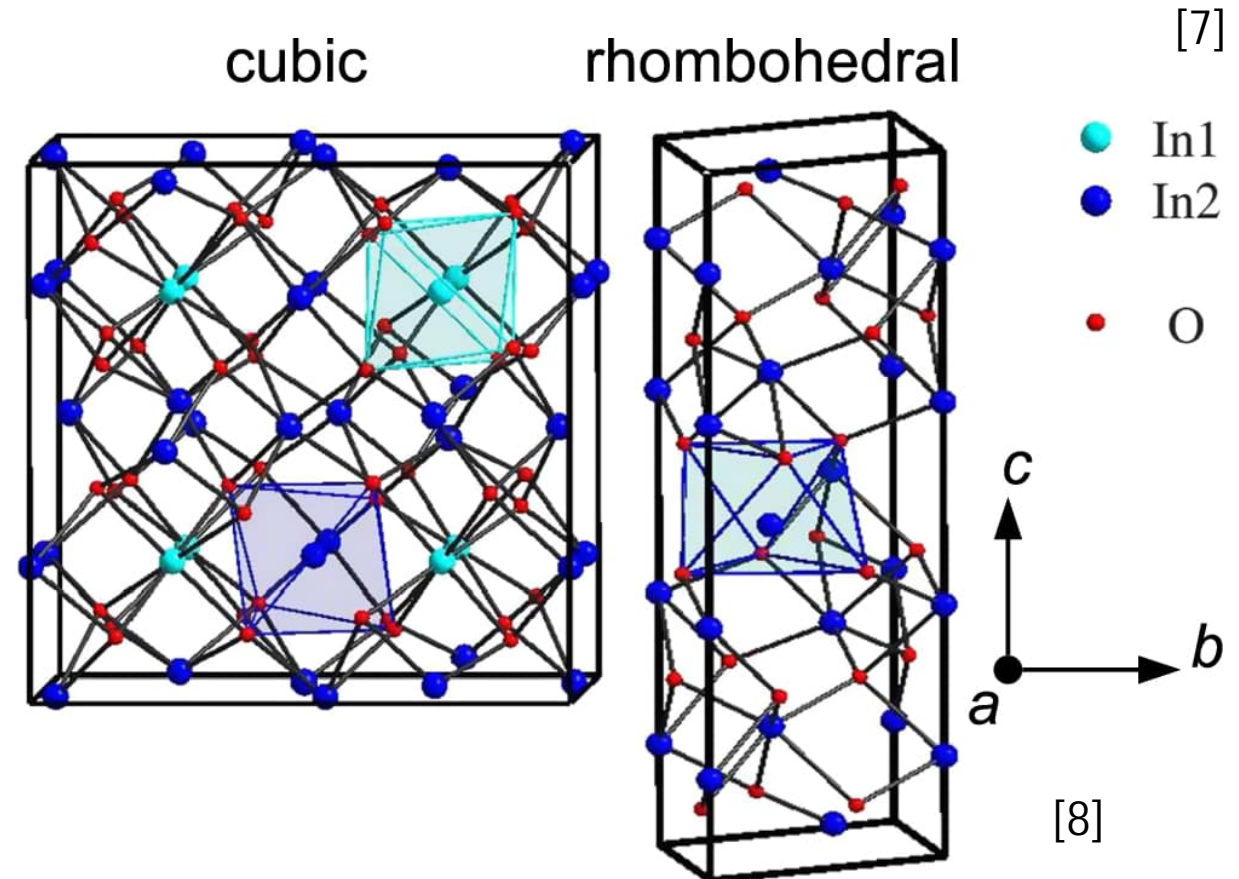
# Indium compounds

# Indium Compounds

- Indium(III)oxide  $\text{In}_2\text{O}_3$
- Chalcogenides: Indium(III)sulfide
- Compounds with group 15 elements: Indium nitride  $\text{InN}$
- Trihalides
- Organoindium compounds

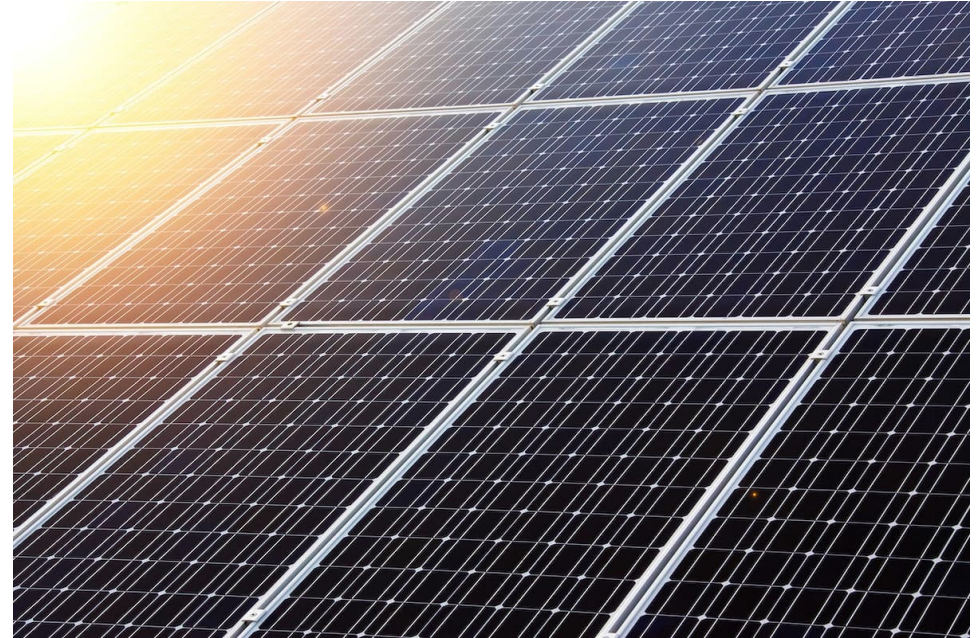
# Indium(III)oxide $\text{In}_2\text{O}_3$

- Cubic or rhombohedral crystal structure or amorphous
- TSO transparent semiconducting oxide (1954)
- Applications:
  - Gas sensors
  - Large band gap semiconductors
  - Indium tin oxide ITO



# Indium Tin Oxide ITO

- Indium(III) oxide doped with tin results in highly conductive Indium Tin Oxide (ITO)
- Typical composition:  $\text{In}_2\text{O}_3$  (90 w-%) and  $\text{SnO}_2$  (10 w-%)
- TCO Transparent conductive oxide
  - Transparent electrodes
- Thin films
  - Vapor deposition methods
- Applications:
  - Solar cells
  - Touch screens
  - Light-emitting diodes (LEDs)



[9]



[10]

# Indium chalcogenides

- Compounds with S, Se, Te
- Large amount of polymorphs
- Indium sulfide  $\text{In}_2\text{S}_3$ 
  - Cubic, tetragonal, layered
  - Semiconductor
- Applications:
  - Optoelectronics

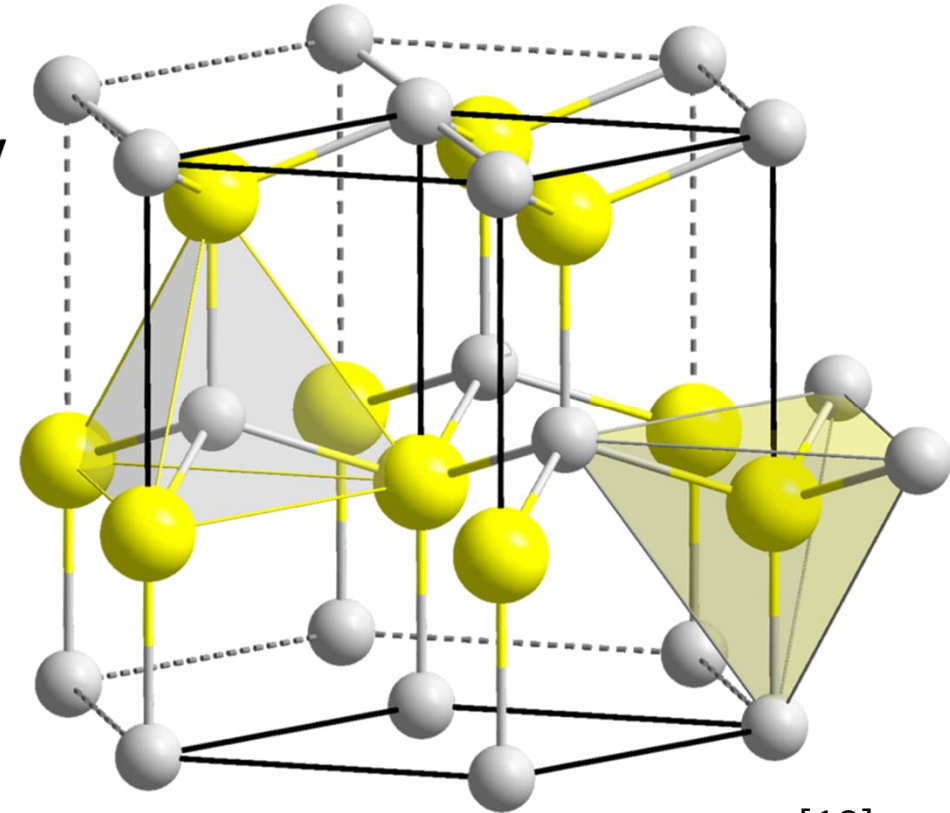


[11]



# Indium Nitride InN

- Hexagonal crystal structure
- Semiconductor with a small band gap 0.7 eV
- Applications:
  - LEDs
  - Photodetectors
  - Solar cells



[12]

# Applications

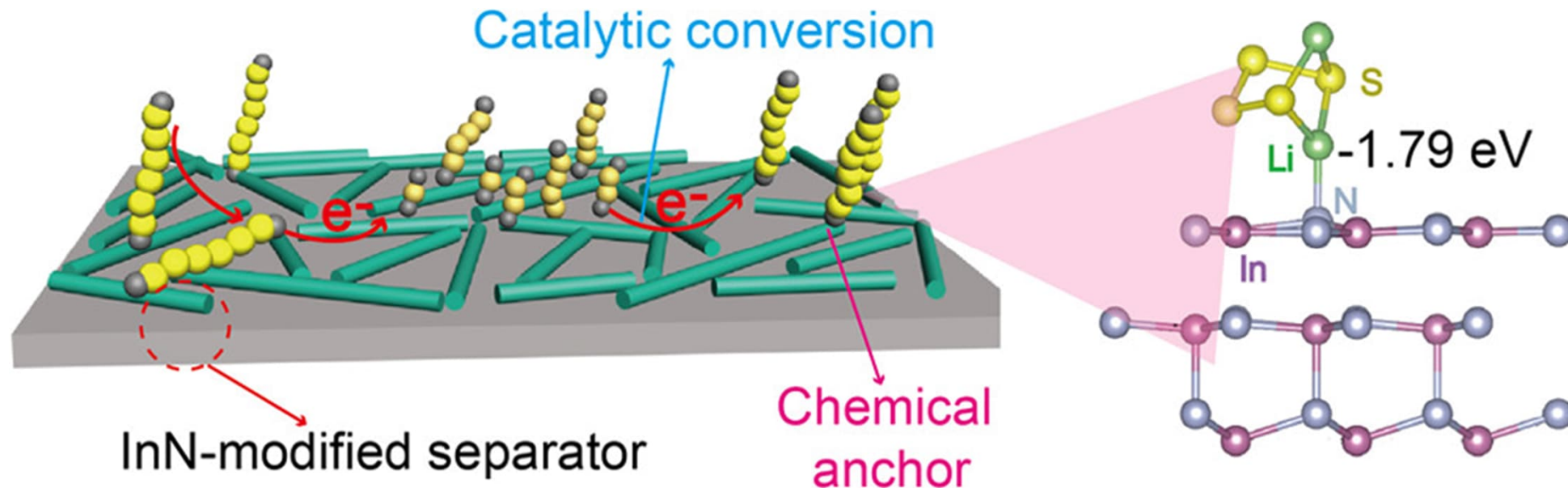
# Indium Nitride for Lithium-Sulfur Batteries

- Lithium-sulfur batteries (sulfur is low-cost and naturally plentiful)
- Problems:
  - Long-chain polysulfides dissolve into the liquid electrolyte (short life time)
- Solution?:
  - Various metal oxides/sulfides have been proposed to trap the lithium polysulfides (poor conductivity leads to poor performance)

Zhang, L.; Xiang, C.; Wan, F.; et al. **Enhanced Electrochemical Kinetics and Polysulfide Traps of Indium Nitride for Highly Stable Lithium–Sulfur Batteries**. ACS Nano 2018, 12(9). P. 9578–9586.

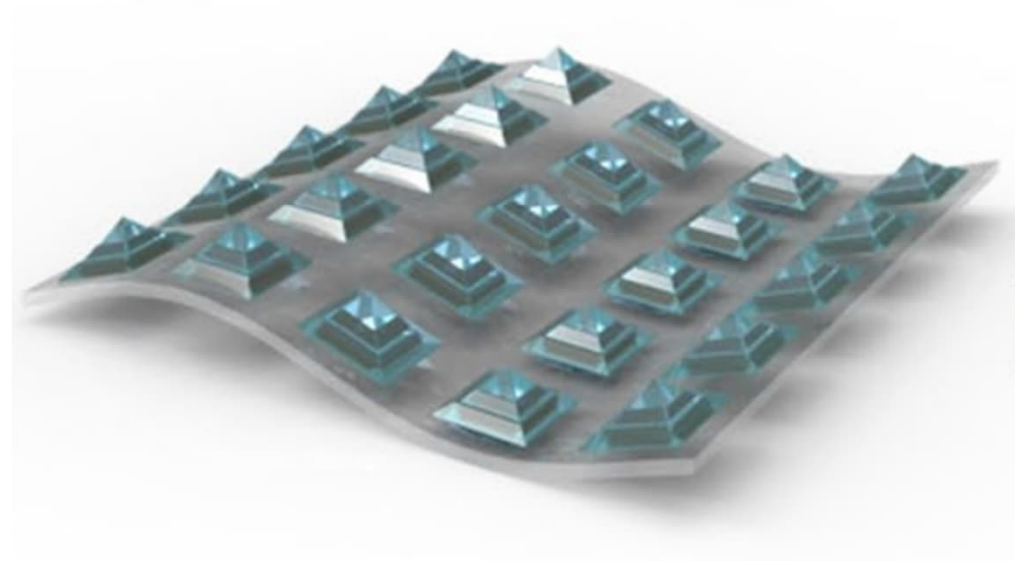
# Indium Nitride for Lithium-Sulfur Batteries

- InN to trap the lithium polysulfides?
  - InN has a narrow band gap and exhibits metal-like behavior
    - The indium cation and electron-rich nitrogen of the InN act both as polysulfide traps through strong chemical affinity



# Flexible sensors from ITO

- Electronic skin
- Both p and T measurements
- Plastic substrate -> Flexibility
- ITO -> Transparency  
Conductivity

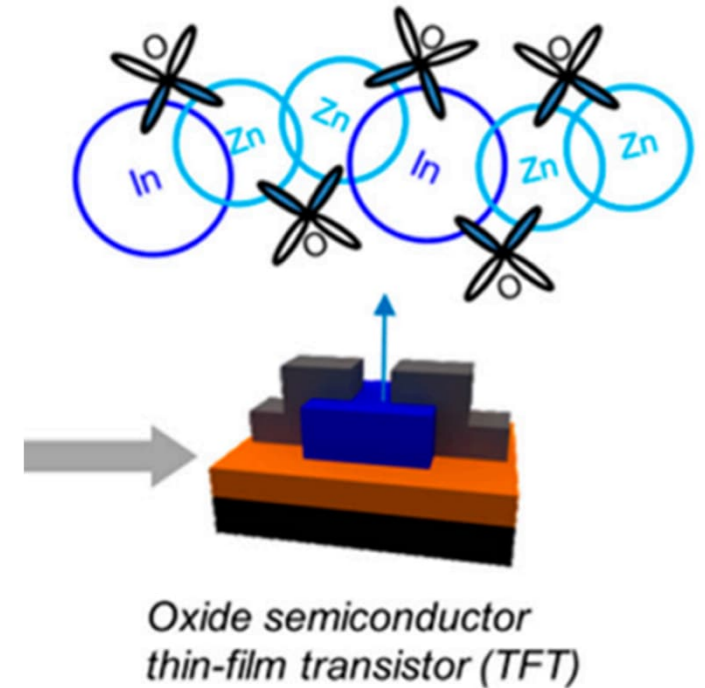


Jung, M.; Vishwanath, S. K.; Kim, J.; Ko, D. K.; Park, M. J.; Lim, S. C.; & Jeon, S. (2019). **Transparent and flexible mayan-pyramid-based pressure sensor using facile-transferred indium tin oxide for bimodal sensor applications.** Scientific reports, 9(1), 14040.



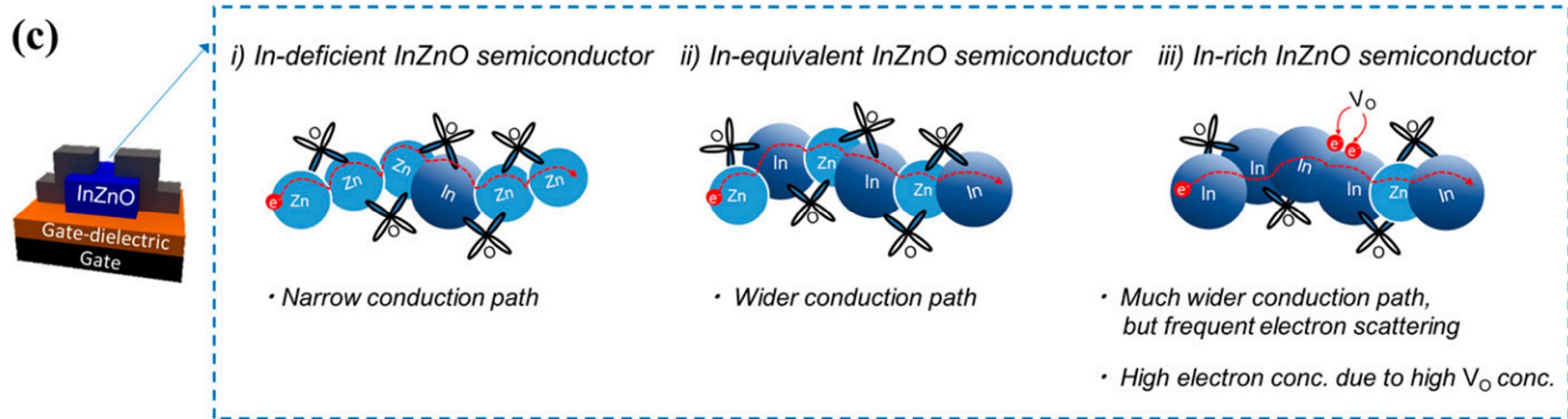
# InZnO as semiconductor

- Semiconducting oxide thin film transistors (TFT)
- pH range where chemically stable:
  - 5-11 for  $\text{In}_2\text{O}_3$
  - 9.5-10.5 for  $\text{ZnO}$
- Electrical conduction pathways
  - outermost s orbitals
- Surface morphology
  - Island-like or smooth (amorphous)



Zhang, X.; Cho, S.W. **Composition Engineering of Indium Zinc Oxide Semiconductors for Damage-Free Back-Channel Wet Etching Metallization of Oxide Thin-Film Transistors**. *Micromachines* 2023, 14, 1839.

# InZnO as semiconductor



Zhang, X.; Cho, S.W. **Composition Engineering of Indium Zinc Oxide Semiconductors for Damage-Free Back-Channel Wet Etching Metallization of Oxide Thin-Film Transistors.** *Micromachines* 2023, 14, 1839.

Thank you!

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