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Indium

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CHEM-E4130

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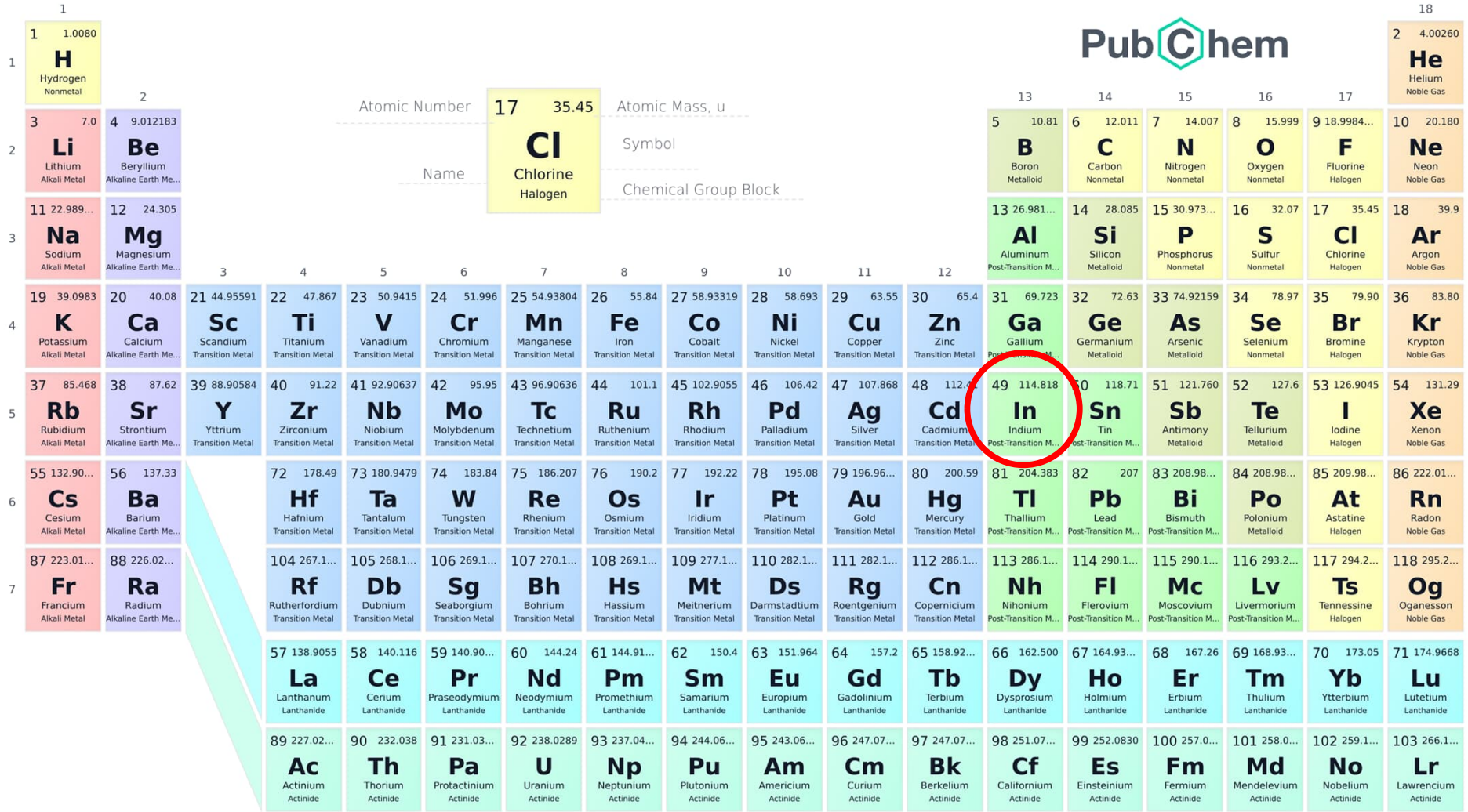
Contents

- 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



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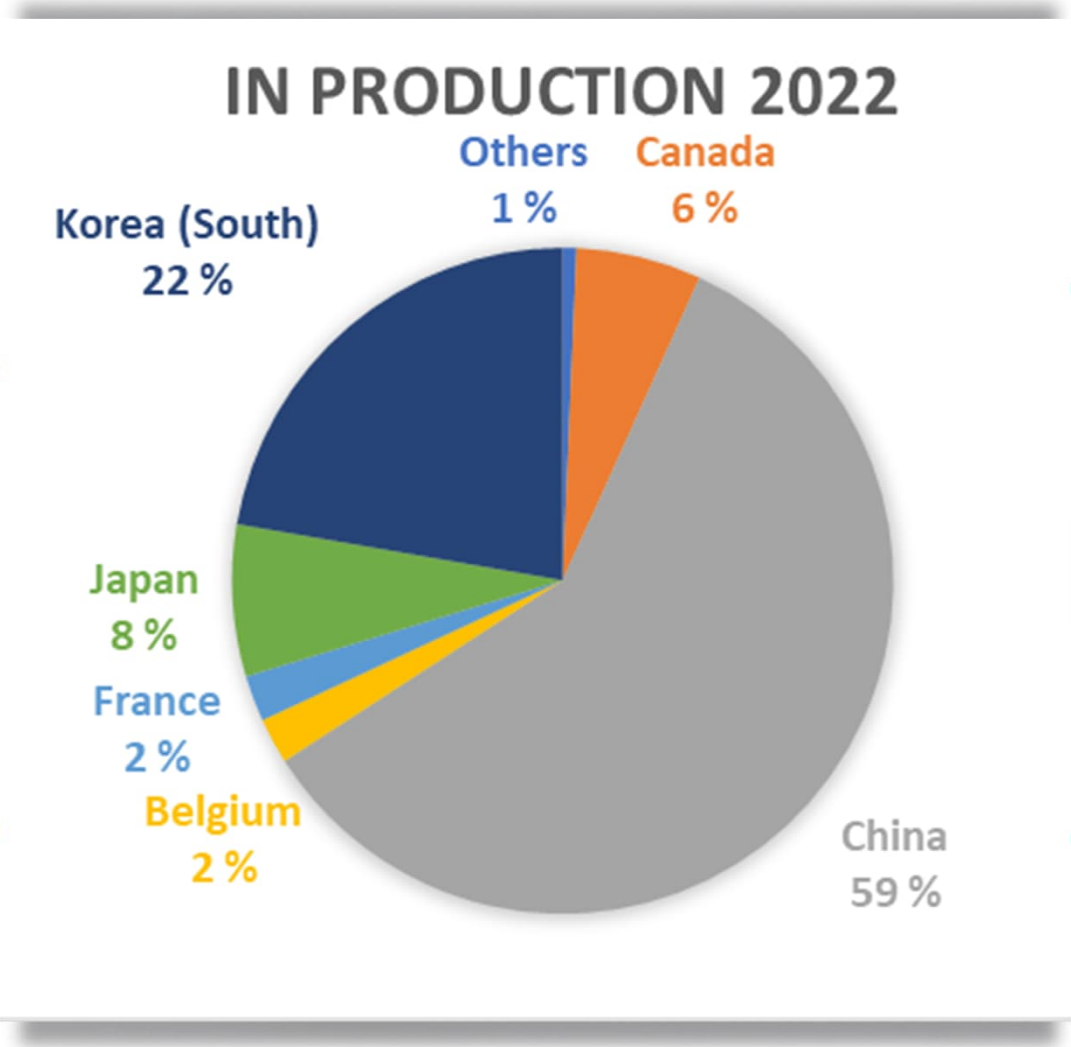
Element

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

Ferdinand Reich &
Hieronymous Richter
1863

Rare
0.2 ppm



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Indigo

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Production 900 tons
per annum

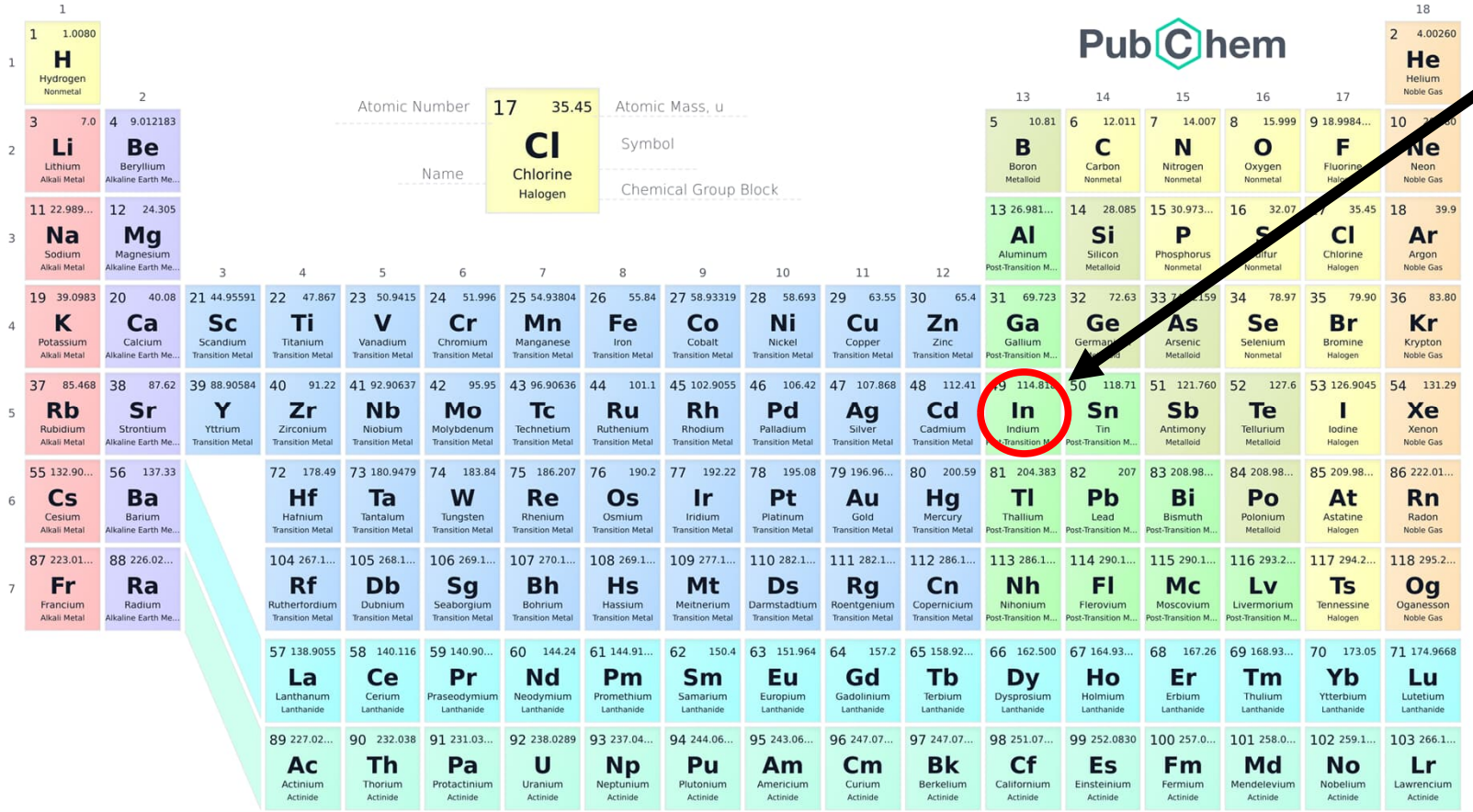
Indium price

~280 USD

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

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

Chemical properties



Electronic configuration:

In: $[Kr]5s^24d^{10}5p^1$

Oxidation states: +1, +3

In^+: $[Kr]5s^24d^{10}5p^0$
In^{3+}: $[Kr]5s^04d^{10}5p^0$

Amphoteric element (dissolves both in acids and alkalies)

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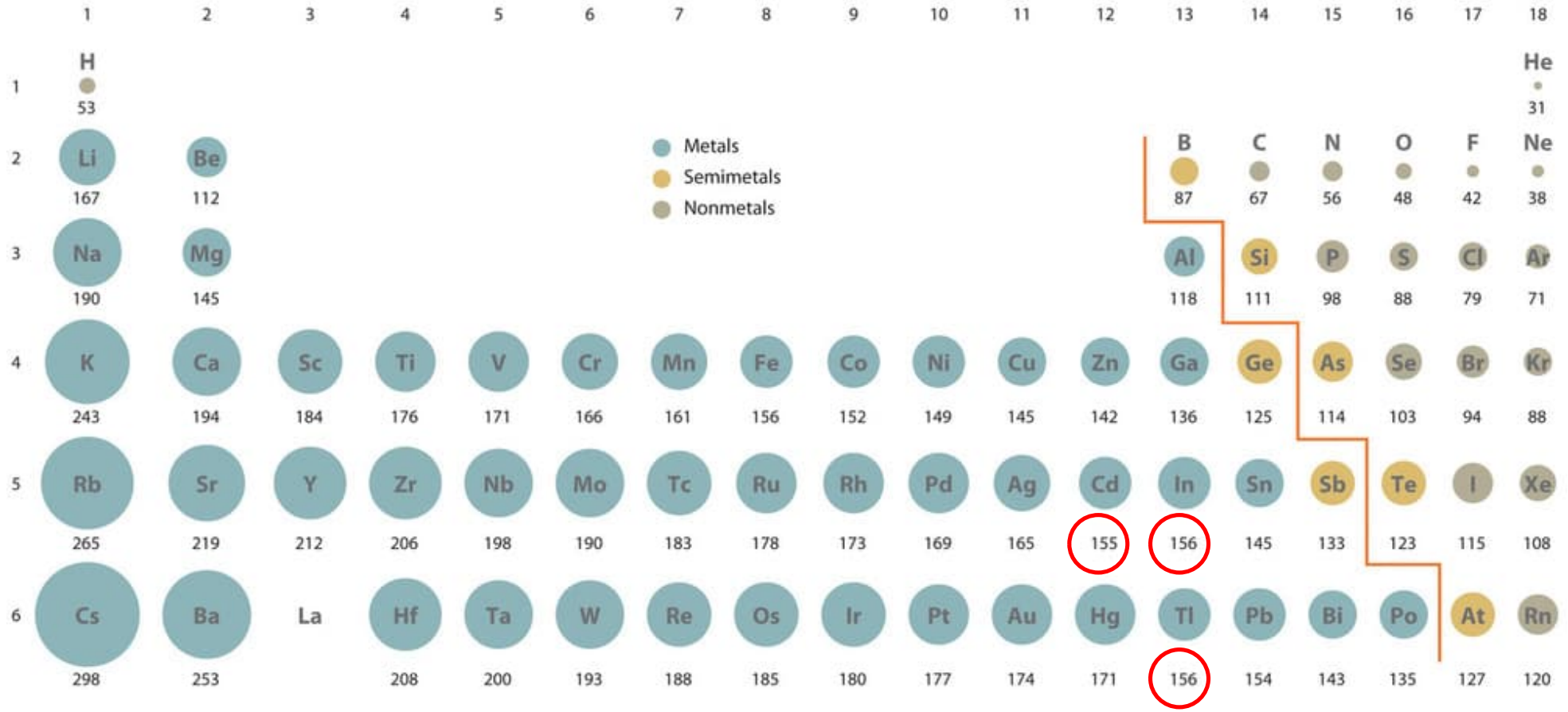
Atomic radius



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Properties

Physical properties

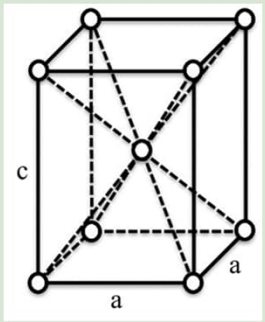
- Melting point 156.60 °C
- Boiling point 2027 °C
- Density 7.31 g/cm^3

Isotopes

- One stable isotope ^{113}In
- 38 unstable isotopes
- Natural indium:
  95.72 % ^{113}In
  4.28 % ^{115}In

Structure

- Crystal structure: Body-centered tetragonal



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

Indium compounds

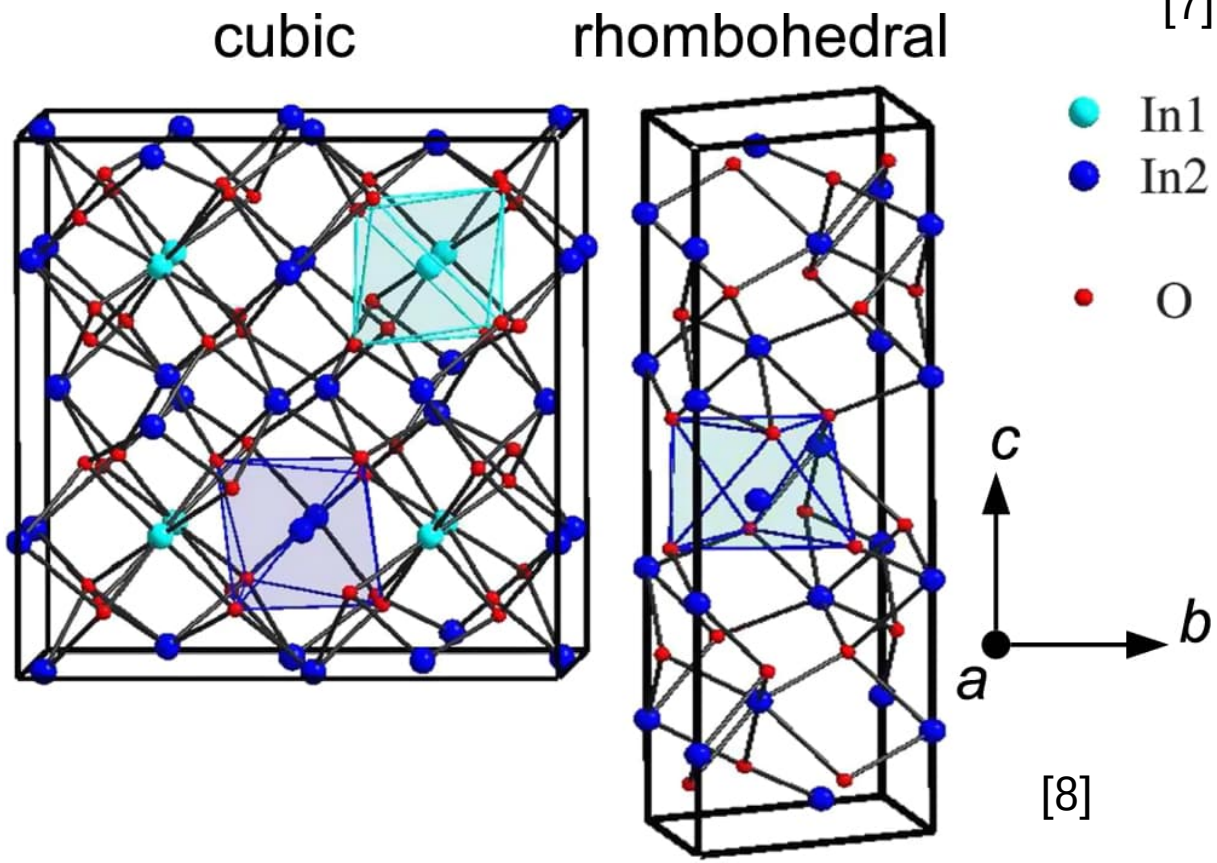
Indium Compounds

- Indium(III)oxide In_2O_3
- Chalcogenides: Indium(III)sulfide
- Compounds with group 15 elements: Indium nitride InN
- Trihalides
- Organoindium compounds

Indium(III)oxide In_2O_3

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

[7]



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Indium Tin Oxide ITO

- Indium(III) oxide doped with tin results in highly conductive Indium Tin Oxide (ITO)
- Typical composition: In_2O_3 (90 w-%) and SnO_2 (10 w-%)
- TCO Transparent conductive oxide
  - Transparent electrodes
- Thin films
  - Vapor deposition methods
- Applications:
    - Solar cells
    - Touch screens
    - Light-emitting diodes (LEDs)

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Indium chalcogenides

- Compounds with S, Se, Te
- Large amount of polymorphs
- Indium sulfide In_2S_3
  - Cubic, tetragonal, layered
  - Semiconductor
- Applications:
  - Optoelectronics

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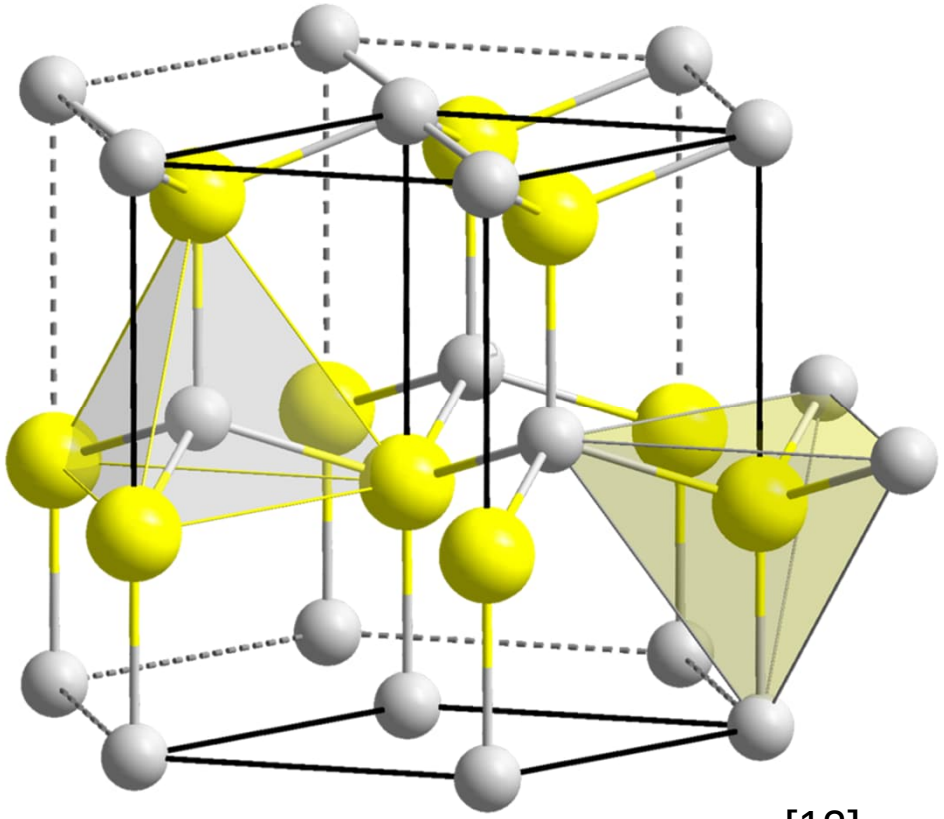
Indium Nitride InN

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



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Applications

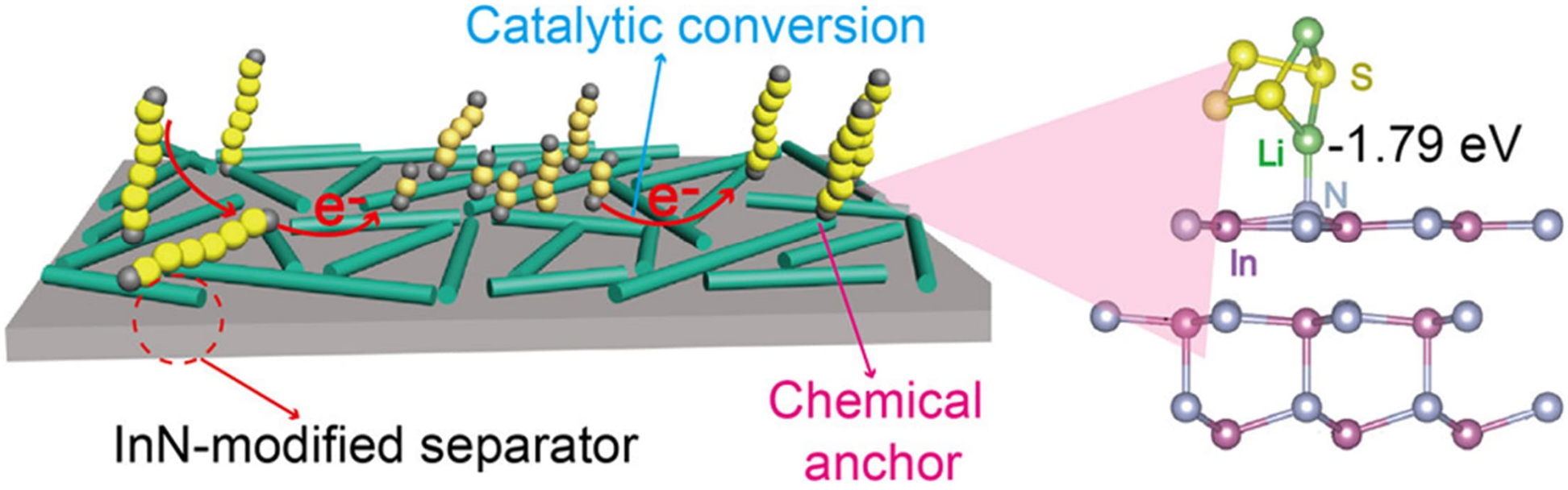
Indium Nitride for Lithium-Sulfur Batteries

- 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.

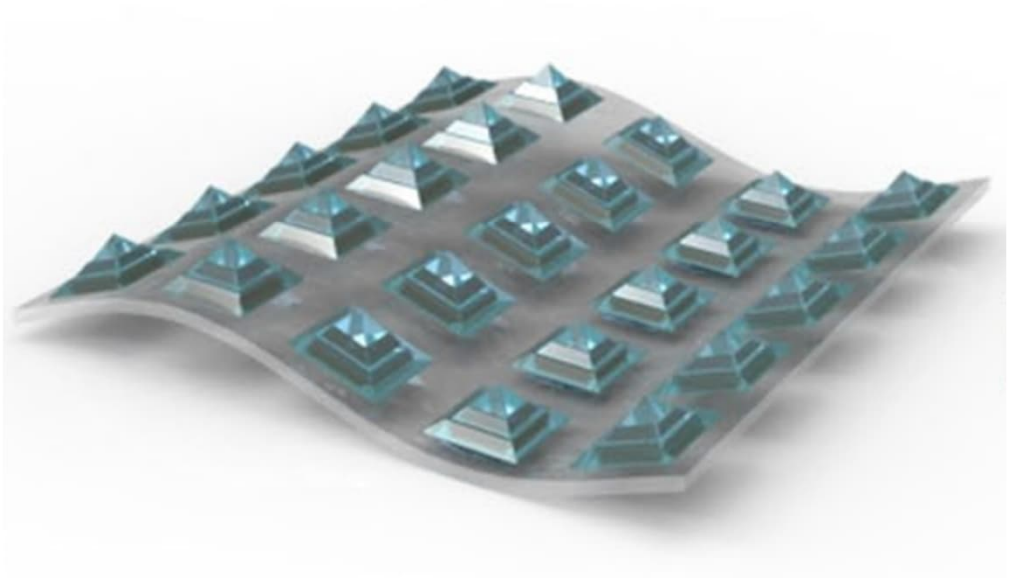
Indium Nitride for Lithium-Sulfur Batteries

- 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

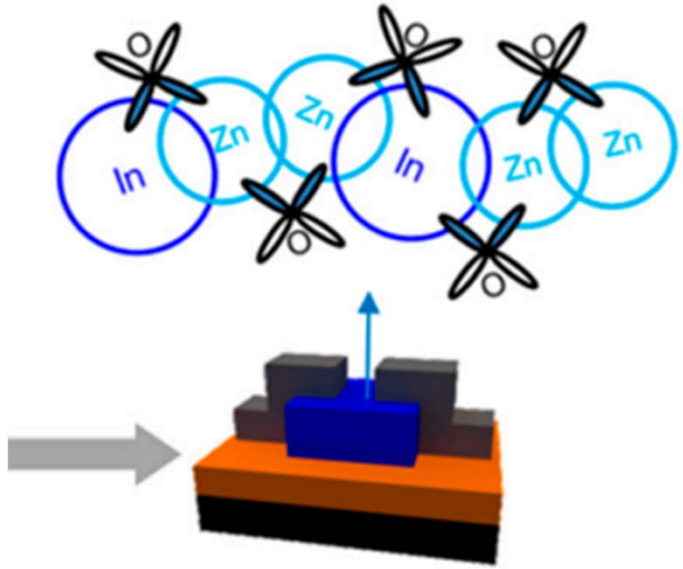
- Electronic skin
- Both p and T measurements
- Plastic substrate -> Flexibility
- ITO -> Transparency
  Conductivity



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

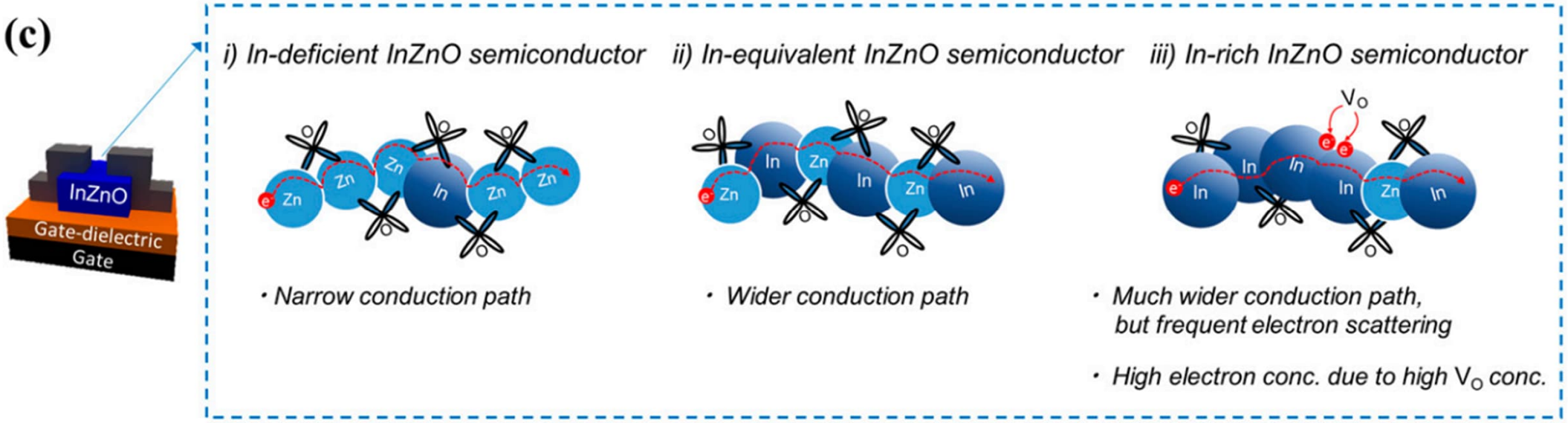
- Semiconducting oxide thin film transistors (TFT)
- pH range where chemically stable:
  - 5-11 for In_2O_3
  - 9.5-10.5 for ZnO
- Electrical conduction pathways
  - outermost s orbitals
- Surface morphology
  - Island-like or smooth (amorphous)



Oxide semiconductor thin-film transistor (TFT)

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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