OSC | 11
Ohio Safety Congress & Expo

#354 Indium hazard awareness in high tech manufacturing

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1:15 to 2:15 p.m.

Ohio | Bureau of Workers' Compensation

CDC NIOSH

Indium in the Workplace: An Emerging Hazard

March 31, 2011
Ohio Safety Congress

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Disclaimer

The findings and conclusions in this presentation are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Objective

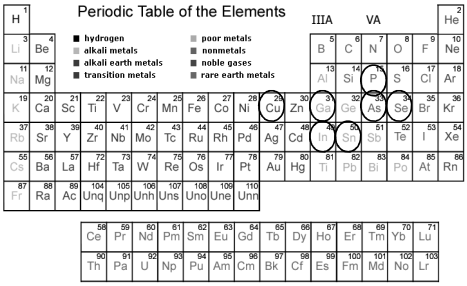
- To discuss indium and its compounds as an example of a relatively unknown material with increasing commercial use and the emergence of an occupational health hazard.

Presentation Outline

- Background on Indium
- Indium Applications
- Health Findings
- Exposure Monitoring
- NIOSH Industrywide Indium Project

Background

Indium – Element No. 49



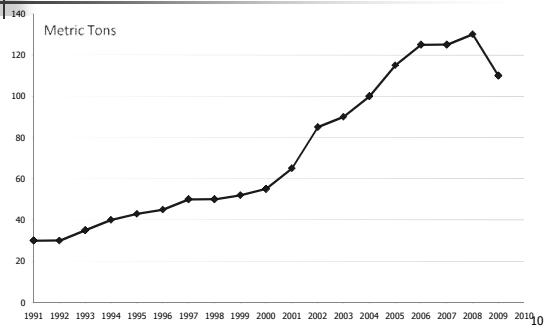
Properties

- Soft, ductile, silvery-white metal
- Low melting point:
  - Indium: 156ºC
  - Lead: 327ºC
- Boiling point: 2072ºC
- Soluble in mineral acids; insoluble in water
- Blue spectral line, indigo → indium
- Expensive ~$500/kg in 2009 (source: USGS)

Forms of Indium

- Metal (In)
- Metal alloys
  - e.g. In:Sn, In:Sn:Cd:Bi:Pb, CIG
- Inorganic Compounds
  - e.g. ITO, In_2O_3, InP, $InCl_3$, InAs, InN
- Metal-organic compounds (e.g. trimethylindium)

U.S. Indium Consumption: 1991-2009



Applications

Indium – Industrial Cycle

- Mining and Smelting
- Secondary Refining
- Commercial Applications
- Reclamation
- Recycling

Mining & Smelting

- Mining
  - Zn ore (sphalerite), <1-100 ppm
  - Zn concentrates produced from ore
  - Only U.S. mine producing Zn conc. is in Alaska
- Smelting
  - Extract crude indium from concentrates.
  - Two In smelters in Canada; none in U.S.
  - Not all Zn mines/smelters produce indium
  - Largest producers in 2009: China, Canada, Japan

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Secondary Refining

- Increase purity of In metal
- Produce In metal alloys
- Form In metal & alloys into bars, wire, foil etc.
- Produce In inorganic compounds
  - Powders (oxide, nitride etc)
  - Salts

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Major Commercial Applications

- Thin Film Deposition
- Sputter Target Production
- Target Bonding
- Photovoltaics
- Semiconductor Industry

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Thin Film Coating

- Deposit a thin film of In, In compound or In alloy onto glass, metal, polymer or other substrate.
- Methods:
  - PVD sputtering (most common)
  - Evaporation
  - MOCVD
- Applications
  - Flat panel displays, solar cells, semiconductor

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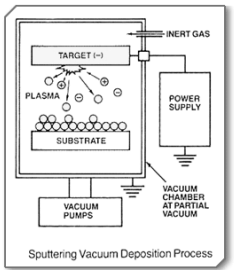
Sputtering: Plasma Vapor Deposition (PVD)

- Target (cathode); Neg. charge
- Plasma created (e.g. argon)
- + ions accelerate toward target
- Collision → momentum transfer
- Target atoms ejected
- Deposit on substrate (anode)
- Chamber sealed, under vacuum
- Uniform deposition desired



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Sputter Chamber Cleaning

- Target material deposits on interior surfaces, shields
- Material must be removed periodically

- Methods
  - Manual scraping, sanding
  - Mechanical sanding, grinding
  - Abrasive blasting (e.g. glove box)

- Exposure potential?

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Sputter Targets

- Planar
  - Target spent at ~25-40%
- Rotary
  - Target spent at ~ 75-90%
- Exposure during target manufacturing?
  - Ceramic targets (e.g. ITO)
  - Metallic targets (e.g. indium)

Planar Sputter Target

Rotary Sputter Target

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Ceramic Target Manufacturing, e.g. ITO

Create & Size Powders

↓

Blend Powders

↓

Cast/Form to Shape – mold, die etc. — Un-Sintered

↓

Pressure and/or Heat (Sinter) to Fuse Powders

↓

Finishing: Grinding, Polishing,Cutting — Sintered

*Co-precipitation techniques also possible

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Target Bonding

- Bonding a sputter target to a backing plate with an indium or indium alloy solder.
- Exposure potential?
  - While handling the solder
  - During finishing steps
  - During de-bonding
  - While finishing ITO target surface

Backing Plates

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Post Thin Film Deposition

- Etching
- Scribing
- Cutting

Exposure Potential?

- Deposition of another TF layer
- Encapsulation

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Photovoltaics

- Two indium uses
  - Semiconductor in flexible thin film solar
    - Copper Indium Gallium Diselenide (CIGS)
  - Transparent Conductive Oxide (TCO) coating
    - CIGS
    - Amorphous silica (a-Si)
    - Cadmium Telluride (CdTe)

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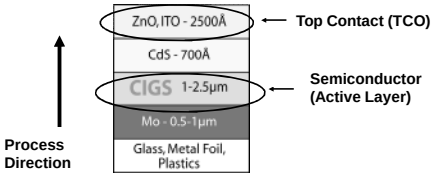
Photovoltaics - CIGS

- Indium-containing materials
  - CIGS layer – active or absorbing layer
  - TCO layer (CIGS and non-CIGS solar cells)



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Semiconductor Industry

- In applications
  - Wafer substrates (e.g. InP)
  - Thin film deposition (e.g. epitaxy)
  - Target bonding (e.g. In metal/alloys)
- R&D

← Prototype IBM optical transceiver chipset made on InP, 2007

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Misc. Applications

- Alkaline batteries – prevent hydrogen build-up
- Fusible links
- Nanomaterials
- Ophthalmic lens "blocker"
- Control rods – pressurized water nuclear reactors
- Hardener in gold electroplating baths
- Radioisotope in medical imaging ^{111}In
- Cryogenic seals

Historical use:

- Corrosion-resistant coating in aircraft engine bearings

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Indium Reclamation & Recycling

- Reclamation
  - Incentive to reclaim indium from scrap, spent targets etc.
  - Mostly outsourced?
  - Exposure potential?
- Recycling
  - E-waste, e.g. FPDs
  - Potential for indium exposure during shredding?
  - Likelihood of reclaiming indium from e-waste?

Photo NY Times, June 30, 2009

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Health Findings

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Japanese Workers

2003	• Case report of interstitial pneumonia, 27-yr old male, wet surface polishing of ITO target plates.
By 2008	• 7 cases of pulmonary fibrosis/interstitial pneumonia
2007, 2008	• Two epi studies (108 Exp/38 Unexp; 93 Exp/93 Unexp.) • Both studies suggested a relationship between serum In levels and lung effects
2009	• Larger epi study of 12 factories & 1 research lab (465 current exposed, 127 formerly exposed, 169 unexposed) • Dose-dependent lung effects associated with In exposure

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Japanese Workers cont.

- Work Processes
  - ITO refining, recycling, processing, sputter target production, wet surface grinding
- Exposure Metric: In in serum[1]

	Unexposed	Former Exposed	Current Exposed	
Mean:	0.56	9.63	8.35	ng/ml

- Proposed Japanese OEL: 3 ng/ml indium in serum
- Absence of industrial hygiene information

[1]Nakano et al. (2009) J Occup Health, 51:513-521

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US Workers

- 2010: Pulmonary alveolar proteinosis reported in two U.S. indium processing workers[3]
- Pulmonary alveolar proteinosis (PAP)
  - Rare lung disease
  - Surfactant components accumulate within the alveoli
  - Results in impaired gas exchange
  - Symptoms: shortness of breath, cough
  - Primary PAP: idiopathic, autoimmune antibodies
  - Secondary: to another disease or an occupational exposure

[3]Cummings KJ et al. (2010) Am J Resp Crit Care Med 181:458-464

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US Workers cont.

- Case 1
  - Hydrogen furnace operator in an indium reclamation process, also crushed ITO materials.
  - Employed March 1999, died 2006
- Case 2
  - ITO department, castings sanded before firing.
  - Employed Jan 2004, symptoms Sept. 2005
  - Positive for an autoantibody (GM-CSF): 52.9 µg/L

[3]Cummings KJ et al. (2010) Am J Resp Crit Care Med 181:458-464

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Chinese Worker

- 29-yr old male, employed for 22 months[4]
- Job
  - "Sandblaster" for mobil phone manufacturer - 22 months
  - Sprayed +electrode of LCD with mix of ITO, Al_2O_3, and SiO_2
  - Conditions: poor ventilation, dust mask, 10-hr/day, 6 day/wk
- Diagnosis: pulmonary alveolar proteinosis
- Serum indium level: 151.8 µg/L

[4]Xiao Y-L et al. (2010) Chinese Med J, 123:1347-1350.

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Summary – Human Data

- "Hardly soluble indium compounds"
- Case reports
  - 7 cases interstitial pneumonia – Japan
  - 2 cases alveolar proteinosis – U.S.
  - 1 case alveolar proteinosis – China
- Epidemiology
  - 4 studies of varying size, all in Japan
  - All showing either lung damage, lung changes, or markers of inflammation, lung injury

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Early Animal Studies

- As early as the 1960's, animal studies have shown lung effects from exposure to indium compounds.
- Effects included:
  - Alveolar edema
  - Inflammation
  - Fibrosis
  - Alveolar proteinosis
- Effects can be compound dependent.

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Recent Animal Studies: Hamsters

- Chronic lung toxicity studies in hamsters.
- Intratracheal instillation.
- Studied two compounds at a time.
- All indium compounds showed pulmonary toxicity.
  - InAs > InP
  - InP > ITO
  - ITO > In_2O_3
- Are differences related to:
  - Solubility? Clearance from the lung?

Tanaka et al. 2010 J Occup Health; Tanaka et al. 2002 J Occup Health; Tanaka et al, 1996, Fukuoka Acta Med.

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Recent Animal Studies: Inhalation, Rats

Inhalation Concentration of ITO or IO, mg/m^3

2-week	0	0.1	1	10	100
13-week	0	0.1	1		

26-week follow-up

- Exposure: 6 hr/day, 5 days/wk
- Aerosol MMAD: 1.9 – 3.7 µm
- Measured whole-blood indium level, LOD= 0.5 µg/L

Nagano et al. J Occup Health, 2011

Inhalation, Rats: Findings

- 2-wk: alveolar proteinosis, infiltration of alveolar macrophages and inflammatory cells, alveolar hyperplasia
- 13-wk: similar lung lesions, some worse than 2-wks
- 26-wk : fibrosis of alveolar wall

Key Findings

- Alveolar proteinosis found at 13 wk at 0.1 mg/m^3 (the TLV)
- Blood In levels at 13-wk below Japanese OEL of 3 µg/L
- ITO affected lung more severely than IO

Nagano et al. J Occup Health, 2011

Sintered Indium Tin Oxide

- 4 groups of rats, pharyngeally administered a dose of:

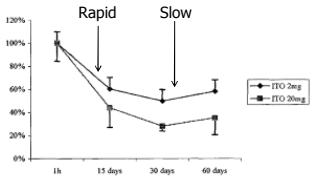
Sintered 90:10 Mix Indium Oxide: Tin oxide > Indium Oxide > 90:10 Mix Indium Oxide: Tin oxide > Tin Oxide

- Sintered ITO induced an inflammatory reaction that was greater than $In_2O_3 > In_2O_3 + SnO_2 > SnO_2$
- Only sintered ITO produced free radicals that caused cytotoxicity.

Lison D et al. Tox Sci 108:472-481, 2009

Biopersistence of ITO

- Laloy et al.[2] assessed elimination of ITO particles (2 and 20 mg) from Wistar rats dosed by pharyngeal aspiration.
- Particles eliminated in two phases.
- Higher dose cleared more quickly than lower dose.
- ITO particles biopersistent in the lung.



[2]Laloy et al. (2007) submitted to EPA

Carcinogenicity

- Indium phosphide (InP)
  - IARC Group 2A (probable human carcinogen).
  - High incidence of malignant neoplasms of the lung in male and female rats and mice.
  - Not evaluated in humans.
- ITO
  - In animals:
    - Genotoxicity: increase in micronucleus frequency
    - Reactive oxygen species leading to oxidative stress
    - NTP cancer bioassays pending

Exposure Monitoring

- Environmental
  - NIOSH Method: 7303
  - 37 mm MCE Filter, ICP-AES or ICP-MS
  - Determines elemental In; not specific In compounds
- Exposure Limits (Indium compounds as In)
  - No OSHA PEL
  - ACGIH TLV, NIOSH REL & Cal/OSHA: 0.1 mg/m^3 , 8 hr TWA
- Biological
  - Serum In (most common)
  - Urine, (rarely, ionic compounds)

National Toxicology Program (NTP): Indium Research

- Key Issues
  - Solubility of In compounds
  - Sintered vs. non-sintered ITO
  - Particle size
  - Developmental and reproductive toxicity
  - ITO carcinogenicity
  - Carcinogenic potential of free indium

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NTP Testing Program

- Addresses toxicity data gaps for new or existing materials with human exposure.
- Range of possible health effects can be tested.
- Nomination process for substances.
- Anyone can nominate a substance.
- NIOSH could assist or make the nomination.
- Website: ntp.niehs.nih.gov

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NIOSH Industry-wide Indium Project

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Objectives

- To understand
  - current workplace uses of indium compounds
  - Jobs/tasks with potential indium exposure
  - indium exposure levels in these jobs/tasks
  - exposure control measures

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Participation

- Interested in the full industry-wide spectrum of indium users.
- Can conduct air sampling for indium and provide results
- If interested or know of someone who might be interested, contact:
  - Cynthia Hines, NIOSH
  - chines@cdc.gov
  - 513-841-4453

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Questions?

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