

# INDIUM PHOSPHIDE

## 1. Exposure Data

### 1.1 Chemical and physical data

#### 1.1.1 Nomenclature

*Chem. Abstr. Serv. Reg. No.:* 22398-80-7

*Deleted CAS Reg. No.:* 1312-40-9, 99658-38-5, 312691-22-8

*Chem. Abstr. Serv. Name:* Indium phosphide (InP)

*IUPAC Systematic Name:* Indium phosphide

*Synonyms:* Indium monophosphide

#### 1.1.2 Molecular formula and relative molecular mass

InP

Relative molecular mass: 145.79

#### 1.1.3 Chemical and physical properties of the pure substance

(a) *Description:* Black cubic crystals (Lide, 2003)

(b) *Melting-point:* 1062 °C (Lide, 2003)

(c) *Density:* 4.81 g/cm<sup>3</sup> (Lide, 2003)

(d) *Solubility:* Slightly soluble in acids (Lide, 2003)

(e) *Reactivity:* Can react with moisture or acids to liberate phosphine (PH<sub>3</sub>); when heated to decomposition, it may emit toxic fumes of PO<sub>x</sub> (ESPI, 1994)

#### 1.1.4 Technical products and impurities

No data were available to the Working Group.

#### 1.1.5 Analysis

Occupational exposure to indium phosphide can be determined by measurement of the indium concentration in workplace air or by biological monitoring of indium. No analytical

methods are available for determination of indium phosphide *per se*. Determination of phosphorus cannot provide the required information on occupational exposure.

(a) *Workplace air monitoring*

The respirable fraction of airborne indium, collected by drawing air through a membrane filter in a stationary or personal sampler, can be determined by nondestructive, INAA. This technique has been applied to the determination of indium concentration in ambient air particulates (Kucera *et al.*, 1999). Using irradiation with epithermal neutrons, indium concentrations have also been determined in arctic aerosols (Landsberger *et al.*, 1992).

(b) *Biological monitoring*

Analytical methods capable of determining low concentrations of indium in biological matrices are largely lacking. The sensitivity of those methods commonly used for indium determination in geological and environmental samples, such as hydride generation atomic absorption spectrometry (Busheina & Headridge, 1982; Liao & Li, 1993), GF-AAS with preconcentration (Minamisawa *et al.*, 2003), electrothermal atomization laser-excited AFS (Aucélio *et al.*, 1998) and fluorimetric determination with HPLC (Uehara *et al.*, 1997), is usually not sufficient for measuring indium in biological materials. Recently, indium concentrations in the body fluids of workers exposed to partially respirable particles containing unspecified indium compounds were evaluated by graphite-furnace atomic absorption spectrophotometry (Miyaki *et al.*, 2003). The detection limits of indium in blood, serum and urine were found to be 0.7 µg/L, 0.4 µg/L and 0.4 µg/L, respectively. It was possible to determine indium concentrations in blood, serum and urine of the exposed workers, but those in control subjects were below the limits of detection.

Data on indium concentrations in the body fluids of occupationally non-exposed persons are insufficient to allow a reliable estimate of reference values.

## 1.2 Production and use

### 1.2.1 Production

Indium is recovered from fumes, dusts, slags, residues and alloys from zinc and lead–zinc smelting. The source material itself, a reduction bullion, flue dust or electrolytic slime intermediate, is leached with sulfuric or hydrochloric acid, the solutions are concentrated if necessary, and crude indium is recovered as  $\geq 99\%$  metal. This impure indium is then refined to 99.99%, 99.999%, 99.9999% or to higher grades by a variety of classical chemical and electrochemical processes (Slattery, 1995; Felix, 2003).

Indium combines with several non-metallic elements, including phosphorus, to form semiconducting compounds. Indium phosphide is prepared by direct combination of the highly-purified elements at elevated temperature and pressure under controlled conditions.

Indium phosphide is also obtained by thermal decomposition of a mixture of a trialkyl indium compound and phosphine ( $\text{PH}_3$ ) (Slattery, 1995; Felix, 2003).

Single crystals of indium phosphide for the manufacture of semiconductor wafers are prepared by the liquid encapsulated Czochralski method. In this method, a single crystal is pulled through a boric oxide liquid encapsulant starting from a single crystal seed and a melt of polycrystalline indium phosphide. For specifications that require doping, the dopant (Fe, S, Sn or Zn), is added to the melt before extrusion of the single crystal. High pressure is applied inside the chamber to prevent decomposition of the indium phosphide. The single crystal is shaped into a cylinder of the appropriate diameter by grinding. The crystal is then sliced into wafers (InPACT, 2003).

World production of indium was constant at approximately 200 tonnes/year between 1995 and 1999, and rapidly increased to over 300 tonnes in 2000. Major producers of indium in 2002 and production levels (tonnes) were: China (85), France (65), Japan (60), Canada (45), Belgium (40), the Russian Federation (15), Peru (5) and other countries (20) (Jorgenson, 1997–2003, 2002; McCutcheon, 2001).

Available information indicates that indium phosphide is produced by two companies in Taiwan (China) and one company each in Japan and the USA (Chemical Information Services, 2003).

### 1.2.2 *Use*

Indium phosphide is a semiconductor and is probably the best understood semiconductor after silicon and gallium arsenide. Indium phosphide is used primarily for the fabrication of optoelectronic devices, because it is operating at high efficiency and high power. It is also used in the fabrication of laser diodes, LEDs, heterojunction bipolar transistors for optoelectronic integration, and in solar cells. Indium phosphide is also used in certain niche areas such as high-performance ICs. The use of indium phosphide in field effect transistor ICs is being driven by two application areas: microelectronics, where indium-aluminium arsenide/indium-gallium arsenide/indium phosphide-based high-electron mobility transistors are used in millimetre-wave frequencies; and optoelectronics, where indium phosphide-based field effect transistors are incorporated into long-wavelength optoelectronic components such as lasers and photodetectors in optoelectronic ICs (Materials Database, 2003; Szweda, 2003).

One of the key advantages of indium phosphide is its potential for the fabrication of very small devices. Because indium phosphide and its ternary (InGaAs) and quaternary (InGaAsP) derivatives have relatively higher refractive indices than those of other optical materials, these compounds allow for devices with much sharper and smaller bends. As their energy band gap is also closer to light energy, electro-optical effects are stronger than those in other materials (which again translates into shorter distances and lower drive voltages). As a result, extremely small devices can be produced: dice are typically  $< 5$  mm and for many functions (e.g. lasers, modulators) they are 1 mm or less (Reade Advanced Materials, 1997; CyOptics, 2002).

Japan accounts for about 56% of the consumption of available indium phosphide wafers, and Europe and the USA for 22% each (Bliss, 2001). In 1998, it was estimated that the use of indium for semiconductor applications worldwide was 19 tonnes (McCutcheon, 2001).

### 1.3 Occurrence and exposure

#### 1.3.1 *Natural occurrence*

Indium phosphide does not occur naturally. Indium is present in the earth's crust at concentrations of 50–200 µg/kg and is recovered primarily as a by-product of zinc smelting. Indium is also found in trace amounts in association with sulfide ores of iron, tin, lead, cobalt, bismuth and copper (Beliles, 1994; Slattery, 1995; Blazka, 1998; Slattery, 1999).

#### 1.3.2 *Occupational exposure*

Exposure to indium phosphide occurs predominantly in the microelectronics industry where workers are involved in the production of indium phosphide crystals, ingots and wafers, in grinding and sawing operations, in device fabrication and in clean-up activities. NIOSH estimated that in 1981 approximately 180 000 workers were employed in the microelectronics industry in the USA, with over 500 plants manufacturing semiconductors (NIOSH, 1985). No assessment of occupational exposure is available specifically for indium phosphide.

In a study of workplace exposure to unspecified indium compounds at a factory in Japan (Miyaki *et al.*, 2003), concentrations of indium in blood and urine were determined for workers exposed ( $n = 107$ ) and those not exposed ( $n = 24$ ) to water-insoluble partially-respirable indium-containing particles in workplace air. Concentrations reported (geometric mean  $\pm$  GSD) in blood were  $4.09 \pm 7.15$  µg/L and  $0.45 \pm 1.73$  µg/L in exposed and non-exposed workers, respectively, and in urine were  $0.93 \pm 4.26$  µg/L and  $< 0.4$  µg/L for exposed and non-exposed workers, respectively.

#### 1.3.3 *Environmental exposure*

There are no data available on environmental exposure to indium phosphide.

Indium has been detected in air (43 ng/m<sup>3</sup>), seawater (20 µg/L) and rainwater (0.59 µg/L). Indium concentrations of up to 10 µg/kg have been detected in beef and pork, and up to 15 mg/kg in algae, fish and shellfish from contaminated water near smelters. The average daily human intake of indium is estimated to be 8–10 µg/day and is regarded as minimal (Fowler, 1986; Scansetti, 1992; Blazka, 1998).

## 1.4 Regulations and guidelines

Occupational exposure limits have not been established specifically for indium phosphide. Table 1 presents occupational exposure limits and guidelines from several countries for indium and indium compounds in workplace air.

**Table 1. Occupational exposure limits and guidelines for indium and indium compounds**

Country or region	Concentration (mg/m <sup>3</sup> ) (as indium)	Interpretation <sup>a</sup>
Australia	0.1	TWA
Belgium	0.1	TWA
Canada		
Alberta	0.1	TWA
	0.3	STEL
Quebec	0.1	TWA
China	0.1	TWA
	0.3	STEL
Finland	0.1	TWA
Ireland	0.1	TWA
	0.3	STEL
Malaysia	0.1	TWA
Mexico	0.1	TWA
	0.3	STEL
Netherlands	0.1	TWA
New Zealand	0.1	TWA
Norway	0.1	TWA
South Africa	0.1	TWA
	0.3	STEL
Spain	0.1	TWA
Sweden	0.1	TWA
Switzerland	0.1	TWA
UK	0.1	TWA (MEL)
	0.3	STEL
USA <sup>b</sup>		
ACGIH	0.1	TWA (TLV)
NIOSH	0.1	TWA (REL)

From Työsuojelusäädöksiä (2002); ACGIH Worldwide<sup>®</sup> (2003); Suva (2003)

<sup>a</sup> TWA, time-weighted average; STEL, short-term exposure limit; MEL, maximum exposure limit; TLV, threshold limit value; REL, recommended exposure limit

<sup>b</sup> ACGIH, American Conference of Governmental Industrial Hygienists; NIOSH, National Institute for Occupational Safety and Health