Semiconductor Technology from A to Z

Compound Semiconductors

InP-Based Photonic Devices

Why Indium Phosphide for Photonics

Indium phosphide (InP) has a direct band gap of about 1.35 eV, corresponding to a cutoff wavelength of around 920 nm, making it directly suitable for light generation and detection, unlike silicon, whose indirect band gap prevents efficient light emission. By combining InP with the ternary and quaternary compounds InGaAs (band gap of the lattice-matched composition $In_{0.53}Ga_{0.47}As$ about 0.75 eV) and InGaAsP, which can be grown lattice-matched to the InP lattice constant of 5.869 Å, the band gap and therefore the emission or absorption wavelength can be tuned over a wide range of roughly 0.92 to 1.65 µm.

Of particular importance is coverage of the two central telecommunication windows at 1.3 µm (minimum chromatic dispersion in standard single-mode fiber) and 1.55 µm (minimum attenuation of about 0.2 dB/km in optical fiber). The lattice match between InP and the quaternary InGaAsP layers, with a mismatch well under 0.1 %, ensures that the epitaxial layers grow nearly defect-free, which is critical for device lifetime.

Laser Diodes and Electroabsorption Modulators

Optical data transmission on InP relies mainly on distributed feedback lasers (DFB lasers), in which a periodic grating along the waveguide selects a single longitudinal resonator mode, producing a very narrow and stable emission line with typical linewidths below 1 MHz. For high data rates, the laser is often combined with a separate electroabsorption modulator (EAM), whose absorption edge shifts under an applied reverse bias through the Franz-Keldysh effect or the quantum-confined Stark effect.

The monolithic integration of a DFB laser and a modulator on a single InP chip is known as an electroabsorption modulated laser (EML) and avoids the coupling losses of an external fiber-to-chip connection between two separate components. Commercial EMLs achieve electrical modulation bandwidths of 25 to over 40 GHz, supporting direct data rates of 40 to 100 Gbit/s per wavelength channel, well beyond what is achievable with directly modulated lasers, whose bandwidth is usually limited to a few tens of gigahertz.

Photonic Integrated Circuits (PICs)

Alongside silicon, InP is the most important material system for photonic integrated circuits (PICs), since, unlike silicon, it can combine active devices such as lasers and amplifiers with passive waveguide structures and photodetectors monolithically on a single substrate. A typical InP PIC combines several DFB lasers of different wavelengths, modulators, waveguide multiplexers, and photodiodes on a single chip; commercial large-scale PICs for optical transport networks today integrate several hundred individual photonic functional elements on a chip only a few square millimeters in size, replacing a large number of discretely fabricated and carefully aligned individual components.

Compared to silicon photonics, which benefits from the mature, high-volume CMOS manufacturing infrastructure with wafer sizes up to 300 mm but depends on hybrid or heterogeneously integrated III-V materials for light generation, InP offers the native ability to generate light directly within the same material – though typically on much smaller 2- to 4-inch InP wafers and at correspondingly higher manufacturing cost per chip area. This simplifies the fabrication flow for purely photonic applications, while silicon photonics plays to its strengths mainly in combination with existing CMOS electronics and the scalability of large wafer formats.