Gallium Arsenide (GaAs)

Gallium arsenide is a III-V group semiconductor. It is a dark gray crystal with metallic shine. This material is widely used in infrared optics, opto- and microelectronics.

Doped crystals of gallium arsenide are used in many applications. The introduced atoms may form substitution solutions by replacing gallium or arsenic atoms, or be introduced in pairs substituting adjacent atoms ion the lattice, or reside in interstitial positions. The properties of a doped crystal strongly depend on interaction of the doping agent with the intrinsic defects of the crystal. The crystals used in laser diodes, LEDs, photocathodes and RF generators undergo high silicon doping. In microelectronic applications GaAs is mostly non-doped semi-insulating. [1]

There are a variety of gallium arsenide preparation processes. The crystals can be grown by Liquid Encapsulated Czochralski (LEC) technology, Float Zone (FZ) method, Vertical Gradient Freeze (VGF) and Horizontal Gradient Freeze (HGF) technology.

It is worth noting that only non-doped semi-insulating GaAs is used in optics. In low-power CO_2 lasers operating at 9.6-10.6 μm wavelength, gallium arsenide can be an alternative for zinc selenide and can be used for lenses and beam splitters. Due to their nonlinear optic properties, gallium arsenide crystals can be used in therahertz photonics as THz radiation generators.

Physical and chemical properties GaAs

Density, g/cm³	5.32
Number of Atoms per 1 cm³	2.21 • 10^{22}
Lattice Constant, nm	0.56534
Mohs Hardness	4.5
Young's Modulus, GPa	82.68
Modulus of Volume Elasticity, GPa	75.5
Poisson Ratio	0.31
Crystal Structure Type	Zinc blende
Chemical Stability	Insoluble in water
Atomic Mass	144.63

Thermal properties GaAs

Melting Point, K	1511
Thermal Conductivity, W/(m•K)	55
Thermal Expansion Coefficient, K^{-1}	5.9 •10^{-6}
Specific Heat Capacity @273K, cal/(g•K)	0.076
Thermal Diffusivity, cm²/s	0.44
Debye Temperature, K	360

Electronic properties GaAs

Dielectric constant @300K	10.88
Work function, eV	4.7
Minority carrier lifetime, s	10
Electron mobility, cm²/(V•s)	8500
Hole mobility, cm²/(V•s)	400
Effective mass of electrons, m^*/m_0	$0.068m_0$
Band gap width @300K, eV	1.43
Intrinsic carrier density, cm^{-3}	1.1•10^{-7}
Electron affinity, eV	4.07

Optical properties GaAs

Non-doped semi-insulating GaAs is highly transmissive in mid-IR region at wavelengths between 1 and 15 μm, as well as in THz region (λ = 100-3000 μm).

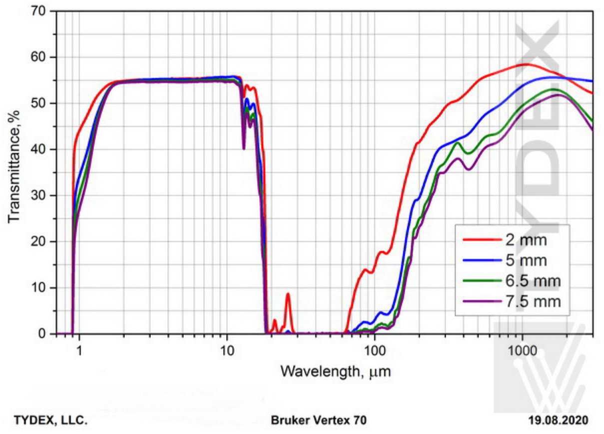

Fig. 1. Gallium arsenide transmission spectra for material thicknesses 2.0, 5.0, 6.5 and 7.5 mm.

In some cases, ex. laser rangefinders, gallium arsenide windows are used at wavelengths of 1.064 and 1.55 μm. These cases require maximum possible transmittance between 1 and 2 μm. If window thickness is fixed, the transmittance depends only on crystal growth method. Our company uses gallium arsenide crystals with maximum transmissivity in this region. Absorption coefficients and detailed transmission spectra for this region are available on demand.

The low slope of the spectrum in fig. 1 between 0.9 and 2.5 μm differs to the materials as germanium and silicon (see fig. 2). It is determined by excitation of deep-level impurities which are always introduced into GaAs crystal during its growth and attaining semi-insulating state.

Besides gallium arsenide can exhibit linear electro-optic effect (Pockels effect). The refractive index of the material changes under external electric field. When an external electric field is applied, the crystal becomes optically anisotropic. Refractive index changes for light polarized parallel to the electric field.

Refractive index variation Δn is described by: $$\Delta n = r \cdot n_0^3 \cdot \frac{E_{BH}}{2}$$

where *r* is the linear electro-optic tensor, n_0 is the refractive index in the absence of electric field, E_{BH} is the strength of external electric field.

As gallium arsenide is a cubic crystal, following components of the tensor r_{ij}: *r41 = r52 = r63 = r*. Coefficients of the linear electro-optic effect for GaAs are given in table below. Superscript *T* or *S* denotes respectively low (zero to sonic) and high frequency coefficients. [2]

λ, μm	Coefficient	Value
0.9	r^S_{41}	1.2 ± 0.05
1.08	r^S_{41}	1.2 ± 0.05
1.15	r^T_{41}	1.43 ± 0.05
3.39	r^T_{41}	1.24 ± 0.04
3.39	r^S_{41}	1.5 ± 0.1

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Gallium Arsenide (GaAs)

4	r^T_{41}	1.1 ± 0.1
10.6	r^T_{41}	1.6 ± 0.1
10.6	r^S_{41}	1.5 ± 0.1
12	r^T_{41}	1.1 ± 0.1

Refractive index dispersion for IR wavelengths [3]:

λ, µm	n	λ, µm	n	λ, µm	n
1.127	3.455	8	3.315	15	2.730
1.15	3.444	9	3.250	17	2.590
2.39	3.326	10	3.309	18	2.410
2.87	3.330	11	3.040	21.9	2.120
5.1	3.300	13	2.970	23	3.182
6	3.320	13.7	2.890	25	3.133
7	3.318	14.5	2.820		

Based on our own measurements using terahertz time-domain spectroscopy, we calculated the dispersion of the refractive index for terahertz frequency range:

λ, µm	n	λ, µm	n	λ, µm	n
110	3.693	700	3.660	1500	3.661
200	3.668	800	3.661	1600	3.661
300	3.662	900	3.661	1800	3.660
400	3.661	1000	3.662	2000	3.661
500	3.660	1200	3.661	2500	3.663
600	3.660	1300	3.661	3000	3.655

Comparison to germanium and silicon

Fig. 2 gives the transmission spectra of the optical-grade (non-doped, semi-insulating) gallium arsenide, optical (high-resistivity, sub-intrinsic) germanium and high-resistivity (over 10 kOhm•cm) silicon. Spectra are shown from the beginning of transparence region (1-2 µm) up to 2500 µm for illustrative purposes and to help selecting the material best suited for your application.

We use gallium arsenide for windows, lenses and prisms in transmission optics for IR and THz frequency ranges. We also manufacture nonlinear optical components of this material.

Please note only ready and polished parts (not raw gallium arsenide) are supplied.

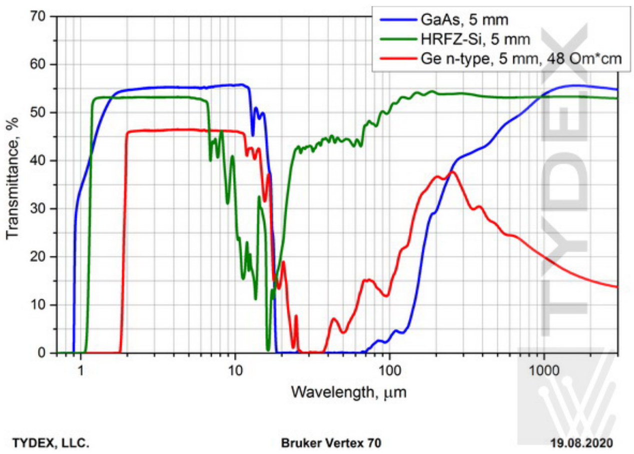

Fig. 2. Transmission spectra of gallium arsenide, silicon and germanium.

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