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Mid-Infrared Optical Response of Heavily Doped GaSb:Te

used for MIR-VCSEL Bragg reflectors

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MOTIVATION

For the design of high quality VCSEL Bragg reflectors the exact knowledge of optical parameters of all layer materials is needed.

Mid-infrared (MIR) optical spectra of GaSb are rather scarce, see data for undoped material collected from various sources [Handbook of optical constants of solids II, ed. by E.D. Palik, Academic Press (1991), p. 597], which have been complemented by the far-infrared reflectance studies [M. Patrini et al., Solid State Commun. **101**, 93 (1997)], and by the near-bandgap (0.7-1 eV) transmittance measurements on Te-doped epitaxial layers for the carrier density below 10^{18} cm^{-3} [C. Ghezzi et al., Semicond. Sci. Technol. **12**, 858 (1997)]. **There are no data available for heavily doped GaSb:Te.**

We have **therefore** studied a series of samples with the Te doping up to $4 \cdot 10^{18}$ cm^{-3}, aiming at the determination of optical constants and the identification of the main contributions to their dispersion in the 3000-5000 cm^{-1} range. In addition, the knowledge of the optical functions enables us to determine film thickness.

EXPERIMENTAL

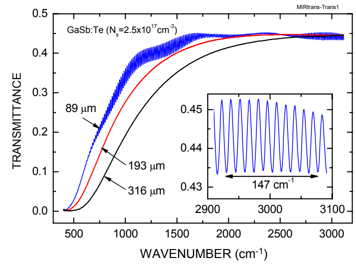
Samples:

2 μm thick GaSb layers have been prepared by MBE on GaSb:Te substrates from Wafer Technology Inc., having the Hall carrier concentration of $(2.2 \pm 0.2) \cdot 10^{17}$ cm^{-3} and mobility of (3300 ± 300) cm^{2}V^{-1}s^{-1}. The samples were grown by a Varian Gen-II solid state MBE machine at the Walter Schottky Institute. The growth temperature was 500°C and the growth rate 0.245 nm/s. Gallium telluride was used as a source to obtain the electrically effective doping levels of $5.0 \cdot 10^{17}$, $1.0 \cdot 10^{18}$, $2.5 \cdot 10^{18}$ and $4.0 \cdot 10^{18}$ cm^{-3}. Concentration of free carriers and mobility were measured by van der Pauw/Hall method on similar layers grown on SI GaAs.

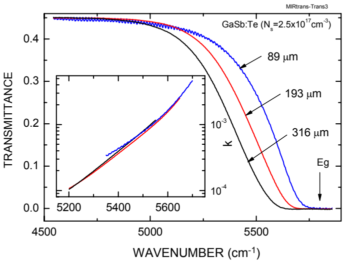
Equipment used for optical measurement:

FTIR reflectance at the angle of incidence of 10 deg, Bruker IFS55 and IFS66 (vacuum), room temperature; evaporated and sputtered gold as reference.
MIR ellipsometer attached to Bruker IFS55.
NIR-VIS-UV reflectance at the angle of incidence of 10 deg, Varian Cary, room temperature.
NIR-VIS-UV reflectance at the angle of incidence of 0 deg, Avantes AvaSpec-2048, room temperature; silicon as reference.

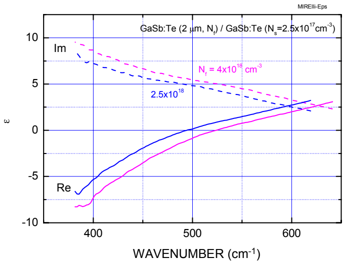
RESULTS



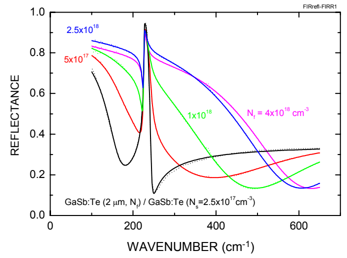
Transmittance spectra of three thinned slabs of the substrate material. The decrease of the transmittance towards **lower wavenumbers** is due to the presence of free-electron plasma and also of the broad absorption band located at ≈ 500 cm^{-1} (see the **ellipsometric measurements** done on samples with higher doping). The inset shows interference fringes for the thinnest sample on expanded scale; since the absorption is fairly low, the periodicity of 14.7 cm^{-1} provides the estimated value of the real part of refractive index $n = 3.83$ at 3000 wavenumbers.



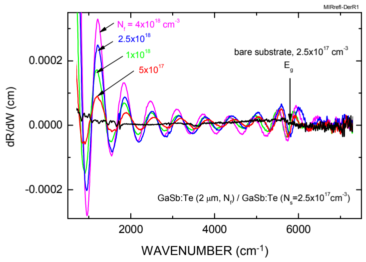
Transmittance spectra of three thinned slabs of the substrate. The decrease of the transmittance towards **higher wavenumbers** is due to the direct gap located at ≈ 5800 cm^{-1}. The inset shows the imaginary part, k, of the refractive index. The nearly exponential tail extends to the photon energies at least 75 meV below the gap. The interference contrast observed for the 89 μm sample is smaller than that at the lower wavenumbers **(see preceding figure),** but still sufficient to obtain a reasonable estimate of the dispersion of n.



Dielectric function ε of two epitaxial films with different doping - **ellipsometrically measured**. The Drude-like response of free-electron plasma dominates at the lowest wavenumbers, and provides the strongest contribution to the dispersion in MIR.



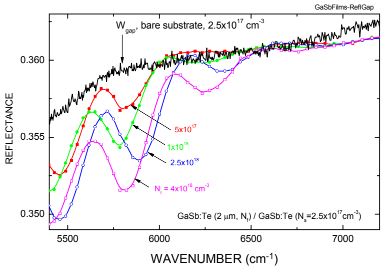
Effect of Te doping on the optical response of GaSb:Te is best seen in the FIR spectra: plasma of free carriers overlaps with the restrahlen band of the polar vibrations of the GaSb lattice (TO frequency of 226.6 cm $^{-1}$). Both free carriers and phonons contribute to lowering of the refractive index in the MIR range. Oscillator strengths obtained from the Drude-Lorentz fit quantify the effect. At lower dopings (≤ $1 \cdot 10^{18}$ cm^{-3}), the spectra are sensitive to the film thickness.



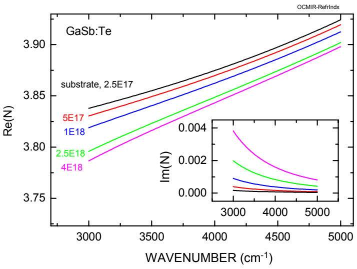
Differentiated reflectance of the substrate and four epitaxial films with different doping. The optical contrast between the film and the substrate increases with doping due to the increase of the spectral weight of free-electrons, and due to the Fermi energy penetrating deeper into the conduction band. The substrate material is partly transparent in a broad range for the low level of doping, even for the thick slabs bearing the epilayers. Thus, the measured signals contain contributions from reflections on the (rough) backside. Even small contributions are significant, since the optical contrast between the substrate and epilayer is small and the patterns produced by the coherent interference inside the epilayer are weak. The spurious contributions of the backsides is essentially removed by the differentiation.

CONCLUSIONS

- ✓ We have obtained detailed data on optical constants of GaSb:Te MBE layers with different doping up to the carrier density of $4 \cdot 10^{18}$ cm^{-3} .
- ✓ The polar vibration at 226 cm^{-1}, and, most significantly, the free carrier plasma, determine the dispersion of optical functions.
- ✓ A significant **Moss-Burstein** blue shift with increasing doping is clearly seen in the bandgap range, due to the changes in occupation probability with the Fermi energy penetrating deeper into the conduction (Γ and L) bands; this also contributes to the dispersion.
- ✓ Precise measurement of the film thickness is viable in the broad range of doping.



Reflectance at the bandgap range of GaSb:Te: Fermi energy penetrates the conduction band and shifts the onset of absorption (Moss-Burstein shift). This leads to a slight lowering of the refractive index in MIR.



Spectral dependence of refractive index of GaSb:Te for several free electron concentrations (in cm^{-3}). The monotonic decrease with increasing doping is mainly due to the Drude response of free carriers, which also dominates in the imaginary part (inset).

Layer thickness d_{opt} calculated from the analysis of interference patterns in our spectra, including the error estimate, compared with the target value d_{growth}.

Te content in the **GaSb:Te** layer (cm^{-3})	**Layer thickness** (nm)		
	d_{growth}	d_{opt}	$error_{opt}$
$5 \cdot 10^{17}$	2000	1914	±10
$1 \cdot 10^{18}$	1970	1950	± 20
$2.5 \cdot 10^{18}$	2000	1980	± 25
$4 \cdot 10^{18}$	1970	1990	± 30

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