Sb-Heterostructure High Frequency Zero-Bias Direct Detection Diodes

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Backward diodes are a version of Esaki tunnel diodes that are useful for mixing and detection. Ge backward diodes in particular have been used as temperature insensitive, zero bias square law detectors, capable of translating low level RF power into DC voltage or current with extreme linearity and low noise. However, Ge diodes are difficult to reproducibly manufacture, are physically fragile, and are limited to the tens of gigahertz range. Planar doped barrier (PDB) diodes can also operate as zero bias detectors, to over 100 GHz, but are difficult to produce in large numbers due to the challenging doping tolerances required. Here we demonstrate specially designed Sb-heterostructure-based backward diodes grown by molecular beam epitaxy. These diodes have superior figures of merit compared to Ge diodes, especially the current density and junction resistance, and are reliably reproducible and physically rugged. Estimates indicate frequency operation comparable or superior to PDB diodes should be achievable. Millimeter wave detector arrays containing thousands of diodes are now feasible for the first time at 94 GHz and above.

The material system of interest here is the InAs/AlSb/GaAlSb nearly lattice matched combination. For small positive bias the electrons tunnel from the InAs through the AlSb barrier into the p-type GaAlSb. At high enough bias the InAs conduction band edge becomes higher than the GaAlSb valence band maximum at the interface and the current is blocked. Negative bias induces the electrons from the GaAlSb valence band to tunnel into the InAs conduction band in a monotonically increasing manner. This asymmetry in the current flow produces the large nonlinearity near zero bias desired for backward diodes.

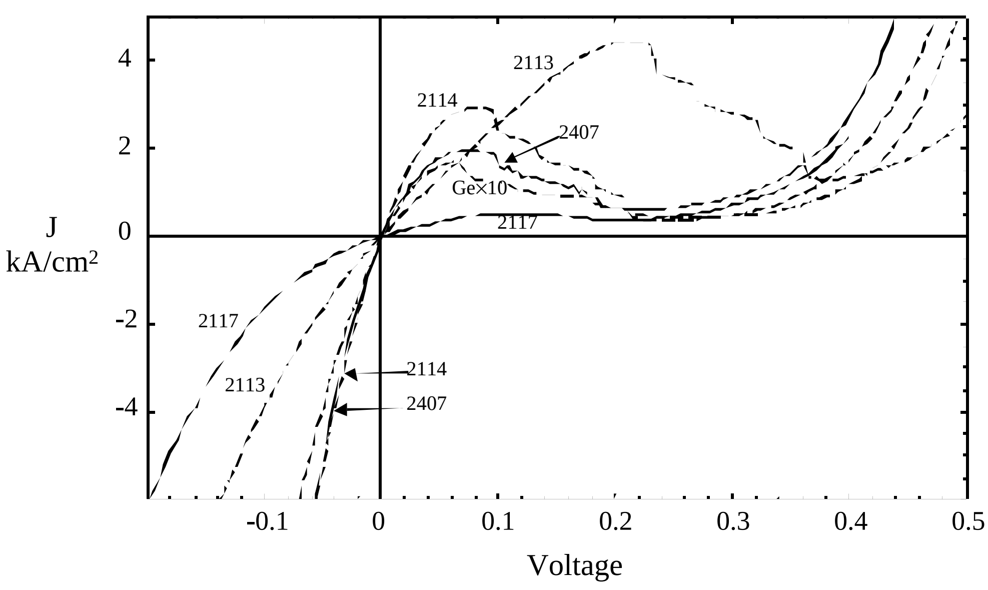
We deposited the InAs/AlSb/GaSb tunnel diode layer structures by molecular beam epitaxy on semi-insulating GaAs substrates. The Table lists the series of samples grown and the Figure shows the I(V)'s of several. Also included for comparison is a similar commercial Ge diode which had been chosen for a square law radiometry application, remote atmospheric temperature measurement.

A large overall current density, consistent with a large backward to forward current ratio, is necessary for maximizing the frequency response of the diode. The substitution of tunneling through the thin AlSb barrier instead of Zener tunneling through the band gap is the critical enabling difference as compared with the conventional Esaki diode. The quantities of most direct relevance in the Table are r_J, the junction resistance, and γ, the curvature coefficient: $r_J = dV/dI$ and $\gamma = d^2I/dV^2/(dI/dV)$, at V=0. r_J is specified for a 100 μm^2 area in the Table, whereas γ is not directly proportional to area. $R_J \equiv r_J \times (100\ \mu m^2/\text{Area})$ has several roles in the design of the circuit, and is very important for determining the voltage sensitivity and the frequency response. Its optimum value depends on the particular circuit implementation. γ should be as large as possible. It contributes directly to the small signal rectifying action of the diode, and thus its current and voltage sensitivity .

Samples 2114 and 2407 have values of γ comparable to the Ge diode, but r_J is an order of magnitude less. Thus for a given desired R_J, determined by circuit considerations, the area can be decreased by this factor relative to the Ge diode, as can the intrinsic diode capacitance (assuming the capacitance per area is similar). Since the parallel current path created by this capacitance is one of the major limitations on frequency response, this decreased value should allow much higher frequency operation, perhaps several hundred gigahertz.

Sample	N_D (cm^{-3})	x (%Al)	V_P (volt)	V_V (volt)	J_P (A/cm^2)	r_J (Ω)	γ (1/volt)
2114	7×10^{17}	0	0.085	0.260	2930	13.0	14.4
2112	2×10^{18}	0	0.125	0.315	3010	20.3	8.56
2113	5×10^{18}	0	0.21	0.380	4460	34.5	4.30
2116	2×10^{18}	20	0.125	0.230	308	261	4.11
2117	2×10^{18}	20, 0	0.115	0.205	505	113	10.9
2407	7×10^{17}	10, 0	0.070	0.230	1980	15.7	19.1
Ge	-	-	0.065	0.245	172	182	15.9

Sample parameters and measurements. V_P and V_V are the peak and valley voltages. J_P is the peak current. r_J is the junction resistance for a 100 μm^2 area. γ is the curvature coefficient.



I(V) characteristics of Sb-based backward diodes and a Ge diode.