128x128 GaAs/$Al_xGa_{1-x}As$ Quantum Well 1 nfrared Photodet ector Focal Plane Array for imaging at 1 S μm

S. D. Gunapala, J. S. Park, T. L. Lin and G. Sarusi

Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

We have developed a first generation 15 μm GaAs/AlGaAs 128x128 quantum well infrared photodetectors (QW1 Ps) focal plane array (FPA) for a staring infrared (IR) sensor system. There are several applications that require very long wavelength, large, uniform, reproducible, low cost, low 1/f noise, low power dissipation, and radiation hard IR FPAs. For example, the absorption lines of many gas molecules, such as ozone, water, carbon rnonoxidc, carbon dioxide, and nitrous oxide occur in the wavelength region from 3 to 18 pm. Thus, IR imaging systems that operate in the very long wavelength IR (VWIR) region (12 - 18 μm) arc also required in many space applications such as monitoring the global atmospheric temperature profiles, relative humidity profiles, cloud characteristics, and the distribution of minor constituents in the atmosphere which are being planned for NASA's Earth Observing System.

'l'he VWIR focal plane arrays we have discussed here in detail consisted of *bound-[()-qua.ritxw)//iQW11's* . The advantage of the bound-to- quasi bound QWI P over the bound-to-continuum QWI J' is that in the case of bound-to-quasibound QWIP the energy barrier for the thermionic emission is the same as it is for the IR photoionization process. In the case of a bound-to-continuum QWIP the energy barrier for the thermionic emission is 10 - 15 meV less than the photoionization energy. 'i'bus, tbc dark current of bound-to-quasibound QWIPs is reduced by an order of magnitude (i.e., $I_d \propto e^{\Delta E/kT} \approx C^{-2}$ for T = 55 K). Four device structures were grown using molecular beam epitaxy on 3 inch GaAs wafers and their well widths L_w vary from 65 to 75 A, while barrier widths arc approximately constant at L_b = 600 A. These QWIPs consisted of 50 periods of doped ($N_D = 2x10^{17}$ cm^{-3}) GaAs quantum wells, and undoped $Al_xGa_{1-x}As$ barriers. Very low doping densities were used to minimize the parasitic dark current. The Al molar fraction in the $Al_xGa_{1-x}As$ barriers varies from x = 0,15 to 0.17 (corresponding to cutoff wavelengths of 14.9 to 15.7 pm). These QWIPs had peak wavelengths from 14 to 15.2 pm. The peak quantum efficiency was 3% (lower quantum efficiency is due to the lower well doping density) for a 45" double pass.

The photoconductive QWIPs of the 128x 128 FPAs were then fabricated by wet chemical etching through tbc photosensitive GaAs/AlGaAs multi quantum well layers into the 1 μm thick doped GaAs contact layer. The pitch of the FPA is 50 μm and the actual pixel size is 38x38 μm^2. Then the random reflectors were fabricated on the top of the detectors and were covered with Au/Ge and Au for Ohmic contact and reflection. Then In bumps were evaporated on top of the detectors for Si multiplexer hybridization. A single QWIP focal plane array was chosen (cutoff wavelength of this sample is 14.9 pm) and bonded to a 128x128 Si multiplexer and biased at V_b = -2.7 V. The focal plane array was back-illuminated through the flat thinned substrate (thickness ≈ 25 μm). Typical dark current-voltage curve and spectral response were measured at T= 55 K, This initial array gave excellent images with 99.9% of the pixels working, dcmonsb-sting the high yield of GaAs technology. The excellent uncorrected photocurrent uniformity of the 16384 pixels of the 128x128 FPA with standard deviation of only σ = 2.4%. The uniformity after correction was 0.2%. As mentioned earlier this high yield is due to the excellent GaAs growth uniformity and the mature GaAs processing technology.

Video images were taken at various frame rates varying from 50 to ?00 Hz with f/2.6 KRS-5 optics at temperatures high as T = 45 K, using a multiplexer having a charge capacity of 4x107 electrons. However, the total charge capacity was not available during the operation, since the charge storage capacitor was partly filled to provide the high operating bias voltage required by the detectors (i.e., V_b = -3 V). The measured noise equivalent temperature difference NEΔT of the 15 μm imaging system is 30 mK at T=45 K for 300 K background. It should be noted that these initial unoptimized focal plane array results are far from optimum. The QWIP device structures was not optimized; the gratings were also not optimized for the maximum light coupling efficiency; no microlenses were used; no antireflection coatings were used; no substrate thinning was used (in the case of VWIR imaging the hybrid was thinned to 25 μm, however, it was not sufficient to improve the light coupling efficiency to small pixel); and finally the multiplexer used was a photovoltaic InSb multiplexer which is certainly not optimized to supply the proper bias and impedance levels required by photoconductive QWIPs. Implementation of these improvements should significantly enhance the QWIP focal plane array operating temperatures (i.e., 77 K for 10 μm and 55 K for 15 pm).