Development of an ultra-sensitive far-infrared detector based on double quantum-well structure

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We are developing an ultra-sensitive far-infrared detector for astronomy as an application of CSIPs - Charge Sensitive Infrared Phototransistors. The CSIPs is fabricated in GaAs/AlGaAs double quantum-well structure (Fig.1). The detection principle of CSIPs is that the upper quantum-well (QW) as a floating gate is charged up by photo-absorption between inter-subbands of the QW, and the conductance of the lower QW is increased as the result of the charge up of the gate. We measure the change of current as a function of photon flux. The great advantage of CSIPs is the huge gain of current amplification, so that the noise performance is not limited by the readout noise. CSIPs are well established for mid-infrared photons, shorter than 30 μm in wavelength. The noise equivalent power (NEP) of CSIPs is achieved 2×10^{-19} [W $Hz^{-1/2}$] at 15 μm with the quantum efficiency of 7%.

However, in the far-infrared region (>20 μm), where is the interesting region in astronomy, much more effort to obtain the high performance CSIPs is required. We try to improve the performance of far-infrared CSIPs with a couple of approaches: designing devices structure and optical coupler. For example, the quantum efficiency in 45μm CSIPs is much smaller than values of 15μm CSIPs by two orders of magnitude because photo-couplers suited for longer wavelengths have not been examined. We investigate the antenna pattern to optimize the efficiency for far-infrared CSIPs with both theoretical and experimental approaches. It is, however, difficult to estimate the antenna pattern that depends on the detectable wavelength and the index of refraction because the reststrahlen band of GaAs hardly changes the index of refraction around 35μm. In our experiments, we improved the sensitivity of 26μm CSIPs by optimizing photo-coupler period for the first time (Fig.2).

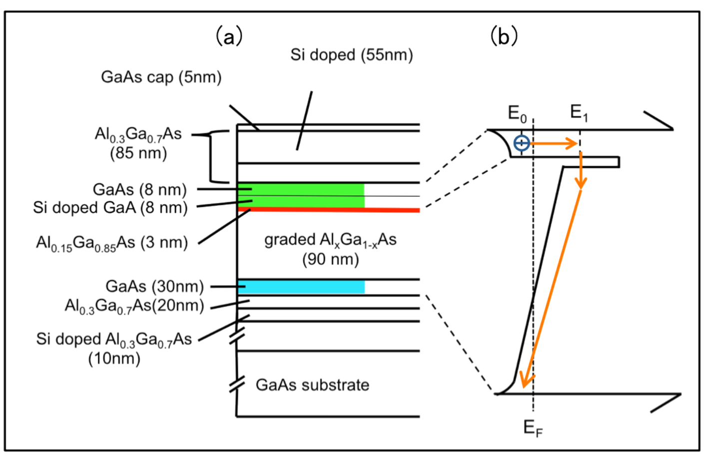

Fig.1. CSIP (a) Crystal structure. (b) Conduction band energy profile.

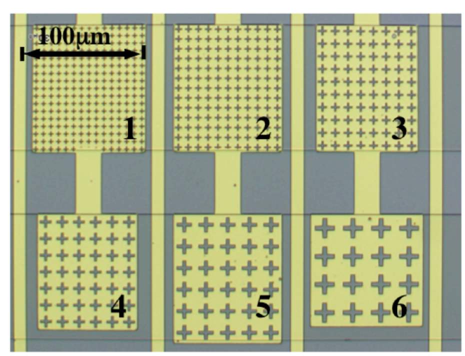

Fig.2. Square lattice metal photo-couplers. We compared the sensitivities between 6 different photo-coupler periods.