Thermal Annealing Study On InGaAs/GaAs Quantum Dot Infrared Photodetectors

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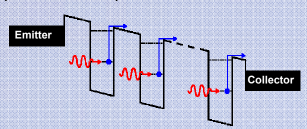
Introduction

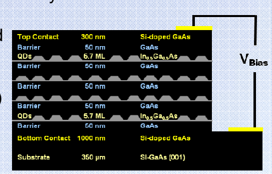
- Self-assembled quantum dots (QDs) can be used in high performance opto-electronic devices



- Quantum dot infrared photodetectors (QDIPs) use intersubband transitions to produce a photocurrent
- Compared with quantum well infrared photodetectors, QDIPs can detect normal-incidence radiation and have reduced dark currents
- Intermixing/interdiffusion can alter the potential profile of the QDs and hence tune the spectral response of detectors
- To induce thermal interdiffusion, rapid thermal annealing (RTA) was performed on our QDIPs at different temperatures
- The optical and electrical performance of the detectors was subsequently characterised
- This technique has potential applications for monolithic integration in optical communication systems and also in fabricating multi-colour QDIPs

Experimental

- Metal-organic chemical vapour deposition (MOCVD) was used to grow 15 layers of $In_{0.5}Ga_{0.5}As$ QDs between GaAs barrier layers. Each InGaAs layer is 5.7 monolayers thick.
- RTA under Ar flow was performed for 30 s at 650°C ≤ T ≤ 800°C
- QDIPs (250 µm × 250 µm mesas) were processed through standard photolithography, wet etching & e-beam metallisation

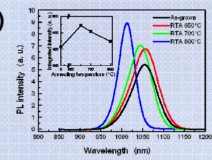


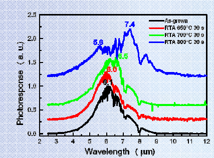
- Photoluminescence, spectral response, dark current, photocurrent and the noise-current spectrum were all measured at 77 K

Results

Photoluminescence (PL) (77 K)

- Blue-shifted after high-temperature RTA but no shift after RTA at 650°C
- Integrated PL intensity increased the most after low-temperature annealing



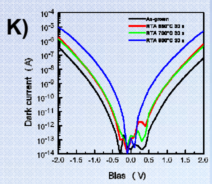


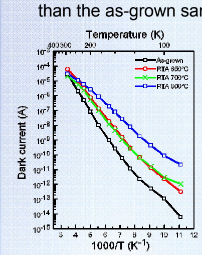
Spectral response (77 K)

- For annealing at temperatures above 650°C, peak response was red-shifted
- After RTA at 800°C, a second higher-energy peak becomes visible

Dark current vs Bias voltage (77 K)

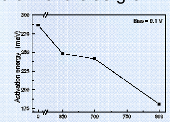
- Annealing at 650°C or 700°C caused only a 10× increase in the dark current
- Samples annealed at 800°C had dark currents 2 orders of magnitude greater than the as-grown sample



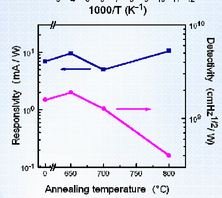


Dark current vs Temperature

- $\log(I_{Dark})$ vs Inverse temperature is mostly non-linear for T < 125 K
- More non-linearity for the annealed samples than for the as-grown sample, for all T



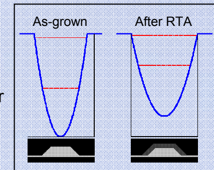
- Arrhenius relation: $I \propto \exp(-E / kT)$
- Activation energy decreased with RTA temperature



Device Performance (77 K)

- Peak responsivity was unaffected by RTA
- Specific peak detectivity was maintained for low annealing temperatures but was degraded after RTA at 800°C

Discussion



Change in the potential profile and QD composition as induced by intermixing

- RTA causes interdiffusion at the QD/barrier layer interface, decreasing the Indium composition in the dots
- The potential profile becomes shallower
  ⇒ The bandgap energy is increased and the PL wavelength is blue-shifted
- The subbands move closer together
  ⇒ The intersubband energy is decreased and the photoresponse is red-shifted
- Reordering of other QD states and their relative absorption strengths reveals a peak at 5.6 µm after annealing at 800°C
- Low-temperature annealing can remove point defects that remain after MOCVD growth. Further annealing can cause strain relaxation in the QDs, and eventually induce extended defects.
  ⇒ Integrated PL is highest after RTA at 650°C but then decreases
  ⇒ Significant increase in dark current after RTA at 800°C
- Defect-related tunneling is non-linear with temperature
  ⇒ Dominates over thermionic emission at low temperatures
  ⇒ The increased, and non-linear dark current in annealed samples might originate from extended defects induced during RTA

Conclusions

- The effects of rapid thermal annealing on 15-layer InGaAs/GaAs quantum dot infrared photodetectors have been investigated
- The photoresponse can be easily tuned with the thermal interdiffusion that results from annealing
- The device performance (detectivity but not responsivity) is only significantly compromised after high-temperature RTA

Acknowledgements

The authors would like to thank M. Aggett, T. Halstead, and D. Gibson for their continuous technical assistance. The financial support from the Australian Research Council is also acknowledged.