Structural, Optical and Spectral Behaviour of InAs-based Quantum Dot Heterostructures

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Structural, Optical and Spectral Behaviour of InAs-based Quantum Dot Heterostructures

Applications for High-performance Infrared Photodetectors

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Preface

This monograph is based on research into the structural, optical and spectral properties of InAs/(In)(Al)GaAs quantum dot (QD) heterostructures, grown by using molecular beam epitaxy (MBE) with an ultimate aim to fabricate high-performance quantum dot infrared photodetectors (QDIPs).

Since the introduction of intersubband photodetectors, much attention has focused on III–V semiconductor-based, MBE-grown quantum dot (QD) heterostructures for medium- and long-wavelength infrared-imaging technology. The three-dimensional carrier confinement possible with QDs is predicted to provide better performance than available from its quantum well counterpart. We optimized various MBE growth parameters using single-layer InAs/GaAs QDs and investigated their structural, optical and spectral properties. Then, we explored the effects of growth pause or ripening time on the properties of dots. The introduction of growth pause during the growth can extend the emission wavelength of the QDs. We have also examined the effects of post-growth rapid thermal annealing (RTA) treatment on properties of single-layer QDs. The next part of the work studied InAs/GaAs bilayer QD heterostructures with very thin ($\sim$7.5–8.5 nm) spacer layers. We have optimized minimum spacer thickness required to grow electronically coupled bilayer QD heterostructures. We have also established the superiority of bilayer QD heterostructures over the single-layer and uncoupled multilayer QD heterostructure in terms of optical and structural properties. We have examined the effects of RTA on bilayer QDs and found remarkable thermal stability of the same at high annealing temperature. Finally, we used sub-monolayer (SML) growth technique to grow QDs. This recent technique is expected to improve the electronics properties of the dots compared to those grown with the conventional Stranski–Krastanov (S-K) growth mode. After an initial study on material characterization, we established that SML QDIPs can be considered as a potential alternative to the conventional S-K QDIPs based on the comparison of the device performance.

Mumbai, India

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Saumya Sengupta received his Bachelor of Science degree in Physics (Honours) from University of Calcutta, India, in 2006; Master of Science degree in Applied Physics from Indian School of Mines University, India, in 2008; and Ph.D. degree from Indian Institute of Technology Bombay, India, in 2014. He has been a postdoctoral research fellow with the Northwestern University, USA, from 2014 to 2016. His research interests include growth and characterization of novel III–V semiconductor materials by using Molecular beam epitaxy (MBE) and Metal-organic chemical vapor deposition (MOCVD) reactors for various opto-electronics applications. He is also involved in the characterization of optoelectronics devices. He has authored more than twenty international publications for various journals and conferences.

Subhananda Chakrabarti received his M.Sc. and Ph.D. degrees from the Department of Electronic Science, University of Calcutta, Kolkata, India, in 1993 and 2000, respectively. He was a Lecturer in the Department of Physics, St. Xavier's College, Kolkata. He has been a Senior Research Fellow at the University of Michigan, Ann Arbor, from 2001 to 2005; a Senior Researcher at Dublin City University, Dublin City, Ireland, from 2005 to 2006; and a Senior Researcher (RA2) at the University of Glasgow, Glasgow, UK, from 2006 to 2007. He joined as an Assistant Professor in the Department of Electrical Engineering, IIT Bombay, Mumbai, India, in 2007. Presently, he is a professor in the same department. He is a Fellow of the Institution of Electrical and Telecommunication Engineers (IETE), India, and also a Member of the IEEE, MRS USA, SPIE USA, etc. He is the 2016 medal recipient of the Materials Research Society of India and was also awarded the 2016 NASI-Reliance Industries Platinum Jubilee Award for application-oriented innovations in physical sciences. He serves as an Editor of the IEEE Journal of Electron Device Society. He has authored more than 250 papers in international journals and conferences. He has also co-authored a couple of book chapters on intersubband quantum dot detectors. Dr. S. Chakrabarti serves as a reviewer for a number of international journals of repute such as Applied Physics Letters, Nature

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Abbreviations

0D	Zero-dimensional
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
A	Ampere
Å	Angstrom
AFM	Atomic force microscopy
Al	Aluminium
As	Arsenic
Au	Gold
BEP	Beam equivalent pressure
BF	Bright field
BQD	Bilayer quantum dot
CCD	Charge-coupled device
CE	Confinement enhancing
cm	Centimetre
D	Detectivity
D*	Specific detectivity
DC	Direct current
DI	De-ionized
DOS	Density of states
EM	Electromagnetic
FFT	Fast Fourier transform
FTIR	Fourier transform infrared spectroscopy
FWHM	Full width at half maximum
Ga	Gallium
Ge	Germanium
gm	Gram
G-R	Generation-recombination
HAADF	High-angle annular dark field

HgCdTe/MCT	Mercury Cadmium Telluride
HNO_3	Nitric acid
H_2O	Hydrogen monoxide, water
H_2O_2	Hydrogen peroxide
H_3PO_4	Phosphoric acid
HRTEM	High-resolution transmission electron microscopy
Hz	Hertz
IIT	Indian Institute of Technology
In	Indium
IPA	Isopropyl alcohol
IR	Infrared
K	Kelvin
keV	Kilo electron volt
kV	Kilo volt
LCC	Leaded chip carrier
LN_2	Liquid nitrogen
LO	Longitudinal optical
LWIR	Long-wavelength infrared
MBE	Molecular beam epitaxy
MCT	Mercury Cadmium Telluride
MeV	Mega electron volt
MOCVD	Metal organic chemical vapour deposition
meV	Milli electron volt
mJ	Milli Joules
ML	Monolayer
mm	Millimetre
Mo	Molybdenum
MQD	Multilayer quantum dot
mW	Milliwatt
MWIR	Mid-wavelength infrared
μm	Micrometre
N_2	Nitrogen
NEP	Noise equivalent power
Ni	Nickel
nm	Nanometre
PC	Photoconductive gain
PID	Proportion, integral and derivative
PL	Photoluminescence
PPR	Positive photoresist
QD	Quantum dot
QDIP	Quantum dot infrared photodetector
QMS	Quadrupole mass spectrometer
QW	Quantum well
QWIP	Quantum well infrared photodetectors
R	Responsivity

RHEED	Reflection high-energy electron diffraction
Sb	Antimony
Si	Silicon
S-K	Stranski–Krastanov
SML	Sub-monolayer
SNR	Signal-to-noise ratio
SQD	Single-layer quantum dot
STEM	Scanning transmission electron microscopy
TCE	Trichloroethylene
TEM	Transmission electron microscopy
TSP	Titanium sublimation pump
W	Watt
XTEM	Cross-sectional transmission electron microscopy