Optimisation of Biexciton binding energy in CdSe/CdTe Core/Shell QD's for MEG

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ELECTRON DEVICES & APPLICATIONS I

Tuesday, August 12 08:30-10:30

8:30-9:00
Invited: Shinichi Takagi
Challenges & Advances of MOSFETs Using High Mobility Material Channels

Complementary MOSFET (CMOS) using high mobility materials using III-V and Ge channels are expected to be one of promising devices for high performance and low power advanced LSIs in the future under sub-10 nm regime, because of the enhanced carrier conduction properties. The advantages of MOSFETs using those materials can basically originate in the low effective mass, which leads to high injection velocity and low scattering rate. However, suppression of short channel effects for applying to the short channel devices strongly demands ultrathin channels with the thickness of 10 nm or less. This requirement needs the deep understanding of carrier transport properties in the inversion layer in such nano-structures composed of the high mobility materials. In addition, since those devices employ MOS devices, the realization of defect-less MOS interfaces is strongly important. However, the understanding and control of MOS interface defects on the high mobility materials are still lacking. In this paper, we address technologies of forming MOS gate stacks, semiconductor channels and source/drain with emphasis on thin equivalent gate oxide, low MOS interface states and quantum well channels and low parasitic resistance. The physical mechanisms of determining current drive of III-V/Ge MOSFETs are discussed in terms of scattering mechanism and influence of MOS interface defects. The impacts of channel strain and the surface orientation on the electrical properties are also examined.

Co-authors: Mitsuru Takenaka

9:00-9:15
Oral: Dax M. Crum
Novel Quantum-Corrected Semi-Classical Ensemble Monte Carlo Simulator for Nano-Scale III-V In0.47Ga0.53As Tri-Gate FinFETs

A promising design space for nonconventional transistor research is nano-scale tri-gate FinFETs using III-V channel materials. FinFET geometries increase gate control and reduce short-channel effects, while III-V materials provide faster carriers than silicon.

To explore this design space, we employ a novel 3D semi-classical ensemble Monte Carlo simulator, accommodating complicated band structures, new 3D device geometries, and a full-range of scattering processes, including polar-optical phonons and carrier-carrier scattering.

Going beyond others, our methodology models all major consequences of quantum confinement via quantum-corrections: redistribution of charge in phase space; quantum-confined phonon scattering; and even confinement-dependent surface roughness scattering.

Moreover, we incorporate a new approach to the Pauli-blocking of scattering for highly non-thermal carrier distributions, which is critical as doping densities move far into the degenerate regime in III-V semiconductors.

We model nano-scale FinFETs showing the imperative need for careful geometric design. We find that long source and drain extensions severely degrade performance in the presence of strong quantum confinement, beyond simple parasitic resistance. In53Ga47As-channel MOSFETS, which is lattice-matched to industry-friendly InP, are compared to Si-channel reference devices, which have slower carriers but also weaker quantum confinement and higher (better) quantum capacitance.

Co-authors: Amithraj Valsaraj, John K. David, Leonard F. Register, Sanjay K. Banerjee

9:15-9:30
Oral: Svetlana Vitusevich
Switching of Scattering Mechanism by Gate Coupling Effect

Silicon nanowires (Si NW) offer unique transport properties and may combine different transport regimes within one device depending on the quality of the device. Here we report on the fabrication of high-quality two-gated (back and front liquid-gated) Si NW FET structures and their advanced transport properties. Voltages were applied to both gates in order to scan through different NW regions by conducting channel. A strong coupling effect between the front liquid and back gate of the Si NW FET was revealed. Utilizing noise spectroscopy, we demonstrate that the shift of the conducting channel from the top interface to the bulk of the nanowire switches the dominant mechanism of 1/f noise from a surface to a volume character. Investigation of transport under different back gate bias conditions allows the behavior of carriers under different scattering mechanisms within one device to be tracked. The observed coupling effect leads to an increase of the FET transconductance accompanied by a considerable reduction of the channel noise. The effect was used to assist the recovery of ultra-small signals from the level below the detection limit of the liquid-gated Si NW FET. The results reflect broad perspectives for utilizing the coupling effect for a novel functionality of advanced nanoelectronic devices.

Co-authors: Sergii Pud, Jing Li, Mykhaylo Petrychuk, Andreas Offenhaeusser

9:30-9:45
Oral: Stanko Tomic
Optimisation of Biexciton Binding Energy in CdSe/CdTe Core/Shell QD's for MEG

In a conventional solar cell the energy of an absorbed photon in excess of the Eg is wasted as heat. Multiple exciton generation (MEG) in colloidal quantum dots (QD) uses this energy to produce additional free charges, increasing the efficiency. An attractive interaction between excitons reduces the threshold for MEG by the biexciton binding energy, Bxx. This has been found to be either small (-10meV) in type I QD or repulsive in type II CdSe/CdTe QD. Here, we show that, by taking into account full CI, optimal CdSe/CdTe core/shell QD can be found that result in large values of Bxx<0. We conclude: (i) it is not possible to predict biexciton binding using the Hartree approximation alone; it can only be predicted with a full CI Hamiltonian; (ii) CI

predicts Bxx = -70 meV for structures with 0.5 nm thick shell; (iii) by ignoring the dielectric confinement, it is not possible to predict biexciton binding for structures with shell thickness > 0.75 nm; (iv) by changing the solvent dielectric constant from 1 to 2 the variation in the Bxx binding energy is as big as 100 meV; (v) a proper calculation of Bxx requires the inclusion of correlations and surface polarization effects but the effect of self-polarization is negligible. The strong biexciton binding found is explained by a stronger reduction in the Columbic repulsion between holes than reduction in the attraction between electrons and holes on the addition of the CdTe shell layer, which is a consequence of 4 fold degeneracy of the h-ground state imposed by symmetry of the structure.

[1] K. S. Novoselov et al., PNAS 2005, 102, 10451.
[2] G. W. Mudd et al., Adv. Mater. 2013, 25, 5714.

Co-authors: Jacek Miloszewski, Tom Walsh, David Binks

9:45-10:00
Oral: Fernando Gonzalez-Zalba
The Sisyphus Impedance at the Zero Dimensional Limit

When a single electron is non-adiabatically cycled through a charge degeneracy point additional components appear on the ac-response of mesoscopic devices. The resistive part known as the Sisyphus resistance as well as the reactive component have been studied in detail for single-electron devices dominated by 3 dimensional statistics [1,2].

Here we present measurements on the Sisyphus effect on a quantum object with a zero dimensional density of states. The dissipative and dispersive components of a few-electron quantum dot system in silicon at frequencies comparable to the electron tunnel rates (Γ) are studied in detail. Differently from traditional rf-SET, the ac-excitation (f) is applied on the top gate of a silicon nanotransistor [3].

The zero dimensional nature of the dot modifies the electron tunnel rates which become independent of bias voltage at milikelvin temperatures. Consequently the high-frequency dissipative and dispersive response is preserved at large bias.

Finally, we explore the dependence of the Sisyphus response with the electron tunnel rates. We demonstrate that a maximum of the resistive signal is achieved when $\Gamma \sim f$ where the dispersive response changes sign.

References

[1] Persson, F.. et al. Nano Letters. 10 953
[2] Cicarelli, C. et al. New J. Phys. 13 093015
[3] Betz, A. C. et al. App. Phys. Lett.

Co-authors: Sylvain Barraud, Andreas C. Betz

10:00-10:15
Oral: Samson Mil'shtein
SiGe HBT with Quantum Well Base

Silicon Germanium Heterojunction Bipolar Transistor, HBT, technology has grown to be a popular solution for many communication, wireless and mobile applications. Interest in the technology continues as higher levels of integration are promised due to the use of Si CMOS fabrication techniques. To further extend SiGe HBT applications, this study introduces a novel design for a SiGe HBT with a quantum well base. The modeling demonstrates an increase in current gain. Potentially, an improvement in noise will be achieved. The SiGe HBT has a silicon emitter n-type doped at 10^19 cm^-3, a base of SiGe (20% Ge) of 150 Angstrom thickness with p-type doping of 10^19 cm^-3, and a silicon collector doped n-type at 10^18 cm^-3. For comparison, an all-silicon BJT is used, where the base contains silicon instead of SiGe. Overall, the SiGe HBT displays a significantly higher maximum current gain. For a common emitter, the base biased at 1.0 V and the collector biased at 2.0 V, the SiGe HBT shows a gain of 40.2 dB in comparison of 24.8 dB for the silicon BJT, with both yielding the same cutoff frequency of 200 GHz. The modeled devices have cross sections of 100 square micrometers.

Co-authors: John Palma, Toshihiko Oka