Material properties in SiGe/Ge quantum wells

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Abstract: Photocurrent measurements in Ge quantum wells and quantum tunneling resonance simulations give the first measurements of effective masses and other parameters for design of high-performance SiGe/Ge quantum well optoelectronics on silicon.

Germanium is increasingly important for integrating photonics into silicon IC technology. Recent demonstrations of quantum wells (QWs) [1] open many new device possibilities, including high-performance optical modulators based on the quantum-confined Stark effect (QCSE) [2]. Relatively little is, however, known about the key properties needed for QW device design. Here we investigate the shifts of multiple different transitions for the first time in such QWs, fitting experimental photocurrent results with quantum-mechanical tunneling resonance calculations. We give the first experimental characterization of the effective masses and direct bandgaps of Ge and Ge-rich SiGe structures including the effects of strain. Though both Si and Ge are indirect gap materials, the QWs produce the QCSE at the Ge direct bandgap [1]. The measured and simulated QCSE shifts of various different transitions are shown in Fig. 1.

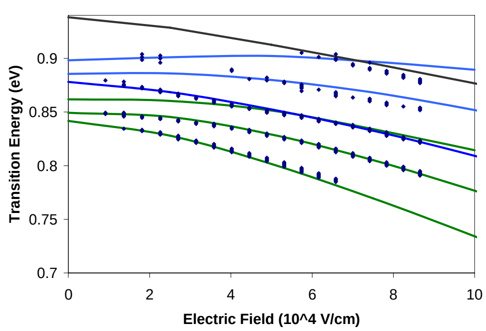

Fig. 1 22.5nm QW - Photocurrent data (dots) and simulations (lines)

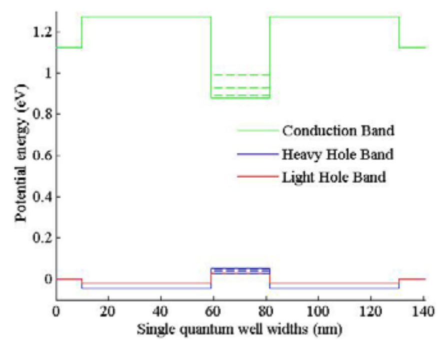

Fig. 2 Illustrative QW dimensions and energy levels

By using a relatively large Ge QW width of 22nm, numerous transitions can be seen, corresponding to three confined electron levels and three heavy hole levels. These energy levels and the valence and zone-center "direct" conduction band energy positions are shown in Fig. 2. The parameters used for this fitting have been printed in Table 1 with their comparable bulk properties.

Table 1: Material properties of bulk materials and strained QWs at 300K (*the electron mass of the relevant Si direct gap has not been experimentally verified. k•p and tight-binding give different results of 0.156 [3], and 0.528 [4], respectively, †Landolt-Börnstein [5])

	Strained Material Properties					Bulk Material Properties		
	m_e	m_{hh}	$E_g(\Gamma)$	ΔE_C	ΔE_{HH}	m_e	m_{hh}	$E_g(\Gamma)$
$Si_{0.16}Ge_{0.84}$ Barrier	0.0647	0.3556	1.283eV	0.38eV	0.114eV	0.061-0.121*	0.325†	1.32(1)eV†
Ge Well	0.0483	0.242	0.827eV			0.042(5)[6]	0.284†	0.797eV†

Through this modeling technique, it was found that the strained heavy hole mass changed significantly compared to the bulk material while the electron mass remained similar, as expected theoretically. These results should now allow reliable device design in strained Ge QWs on silicon substrates.

References:

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