Tensile-Strained Ge Quantum Dots on (111)A Surfaces

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Si and Ge are ubiquitous in electronics, but their indirect bandgaps make them unsuitable for optoelectronic devices. Theory shows that placing Ge under tensile strain reduces its semiconductor bandgap by reducing the Γ-valley in Ge's conduction band faster than the L-valley. Once at ~2% tensile strain, Ge should acquire a direct bandgap. Researchers have therefore tried various ingenious methods to create tensile strain in Ge, but these attempts typically generate strain-induced defects and do not result in viable optoelectronic materials. Our approach to this problem is to synthesize Ge quantum dots (QDs) that self-assemble as a result of biaxial tensile strains on (111) surfaces. We have previously developed a method to grow defect-free GaAs(111) QDs at ~4% tensile strain with molecular beam epitaxy (MBE). Since GaAs and Ge have similar lattice constants, we simply replace GaAs with Ge in these structures. Initial data suggest spontaneous formation of Ge QDs under 3.7% tensile strain, which we anticipate should lead to optically active Ge with a reduced bandgap. We will present results demonstrating control of the structural and optoelectronic properties of tensile-strained Ge QDs with MBE parameters. Specifically, we will report on the effects of growth parameters via atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning tunneling microscopy (STM), and preliminary measurements of their optoelectronic properties.

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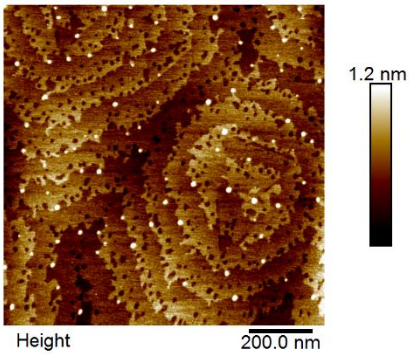

Figure 1. AFM of Ge tensile-strained QDs on InAlAs. This is a 0.2 ML growth, revealing a Volmer-Weber growth mode.

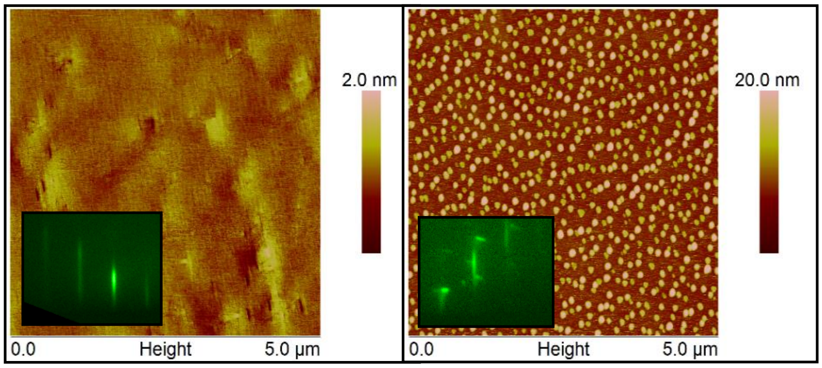

Figure 2. AFM of (left) InAlAs buffer layer without Ge deposition and streaky RHEED inset indicating smooth layers and (right) 2 ML deposition of Ge QDs with a spotty RHEED inset revealing QD growth.

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Supplementary Pages

We were able to obtain clear results indicating tunability and control with respect to growth parameters, as is indicated by the AFM images and corresponding graphs for areal density and QD size. This controllability indicates that the wavelength absorbed for these dots will change with the dot size, as is indicated in the work by Schuck *et al.* [1]. We will report on our own optoelectronic measurements at the conference.

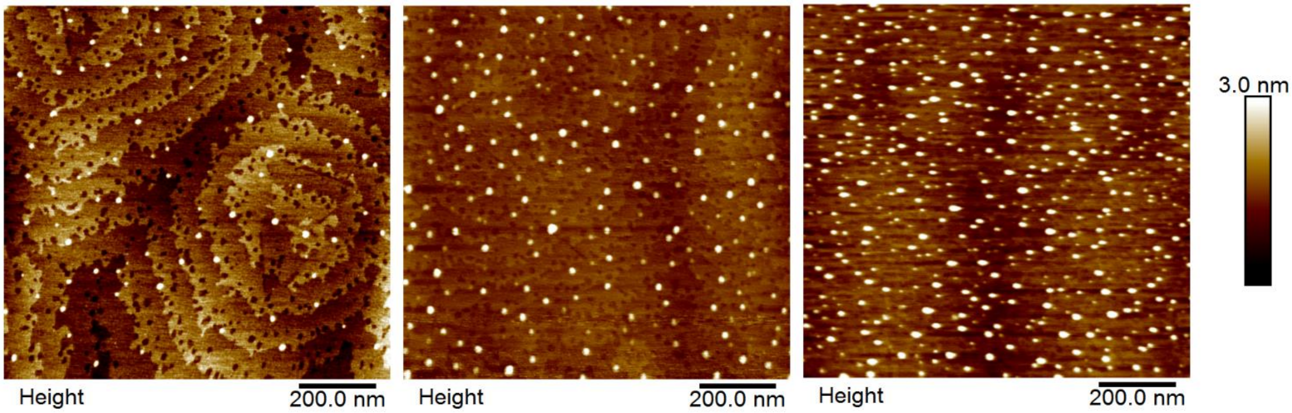
10s Ge deposition
20s deposition
30s deposition

Figure 3. AFM of three different growth lengths under the same experimental conditions. Areal density and dot size increases.

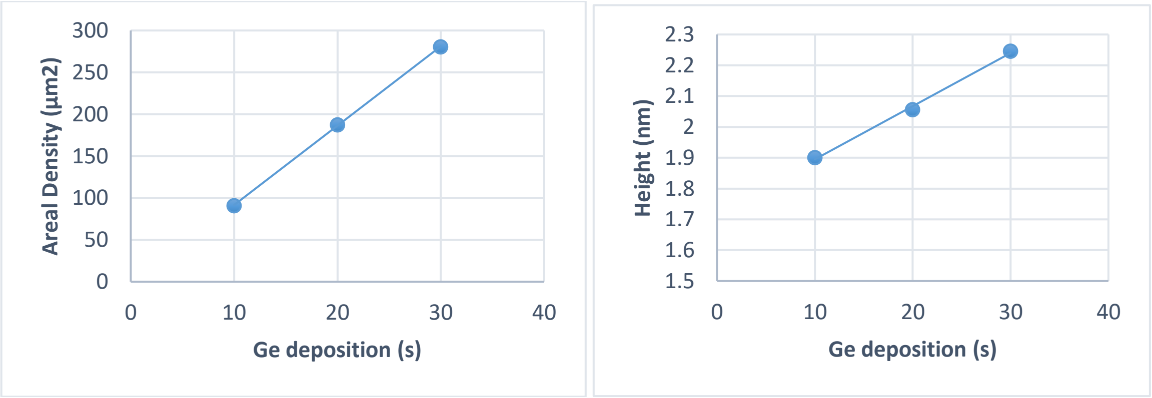

Figure 4. (left) Initial areal density and (right) QD height results for Ge QD growth via MBE.

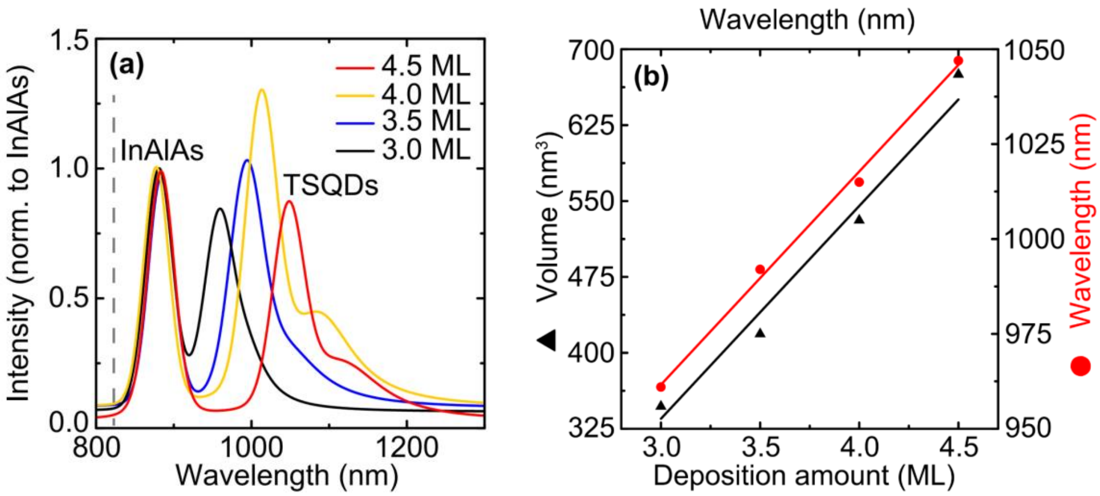

Figure 4. Photoluminescence of GaAs tensile-strained QDs showing an increase in wavelength emission with an increase in dot size [1].

[1] C. F. Schuck, R. A. McCown, A. Hush, A. Mello, S. Roy, J. W. Spinuzzi, B. Liang, D. L. Huffaker, P. J. Simmonds. J. Vac. Sci. Technol., B **36**, 031803 (2018).