Fabrication and regulation of site-controlled Ge quantum dot on pre-patterned silicon microdisks

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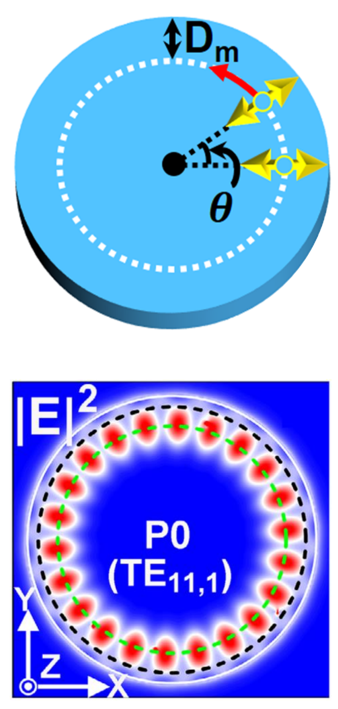
I. Motivation

Ge quantum dots (QDs) on microcavities have been extensively explored for their potential in optoelectronic devices and quantum optics[1]. Efficient interaction (spatial and spectral overlap) between emitters and resonators is the crucial challenge for QDs-cavity system in silicon-based optoelectronic platforms[2,3].



Here, we show a feasible path toward precisely site-controlled growth of Ge QDs in SiGe microdisks by pit-patterned substrate. The position of emitters are designed at the field antinodes of cavity mode through finite-difference time-domain (FDTD) method. The inherent mechanisms are explained via surface chemical potential (SCP) distribution.

II. Manufacturing process

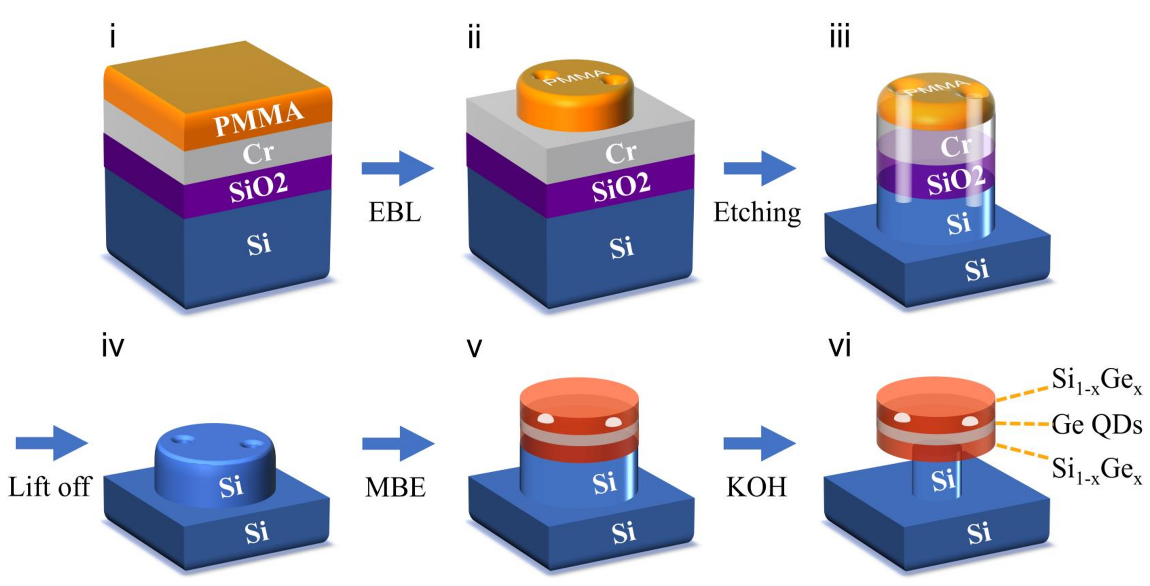


Fig 1. The process flow for accurate site-controlling of Ge QDs in SiGe microdisks. The white columns and hemisphere represent the etched pits and the site-controlled Ge QDs.

III. Optical cavity design

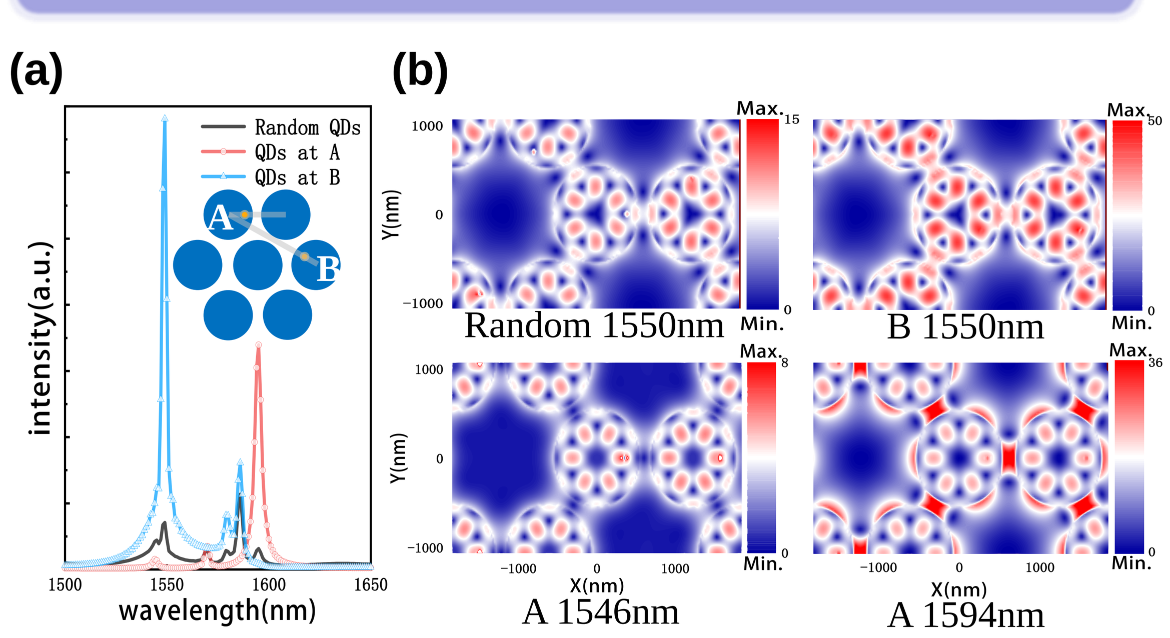


Fig 2. (a) Simulated spectra of the microdisk arrays via FDTD. The inset is the schematic diagram of the system. (b) The electric field (E) distribution for cavity mode in the XY plane.

IV. The surface topography

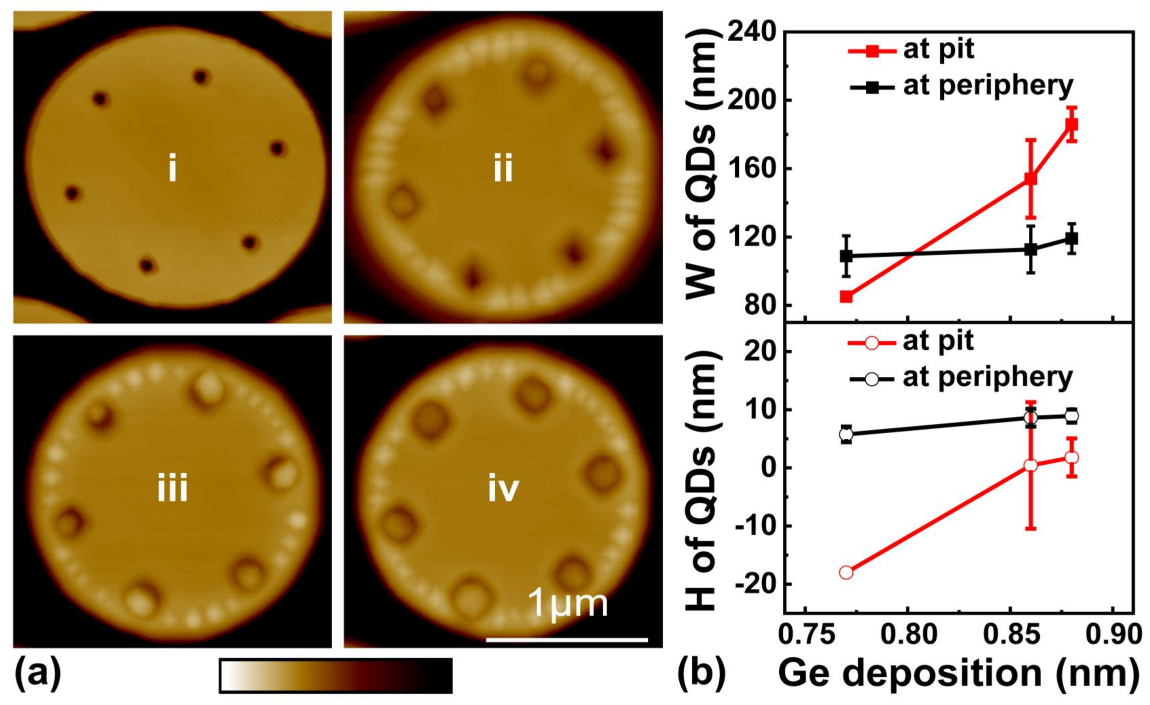


Fig 3. (a) AFM images of Ge QDs on the pit-patterned pillars of different nominal Ge thickness. (b) The dependence of mean height and width of Ge QDs at pits or periphery on the total amount of deposited Ge.
The QDs at pits expand rapidly and the uniformity is significantly improved as growth.

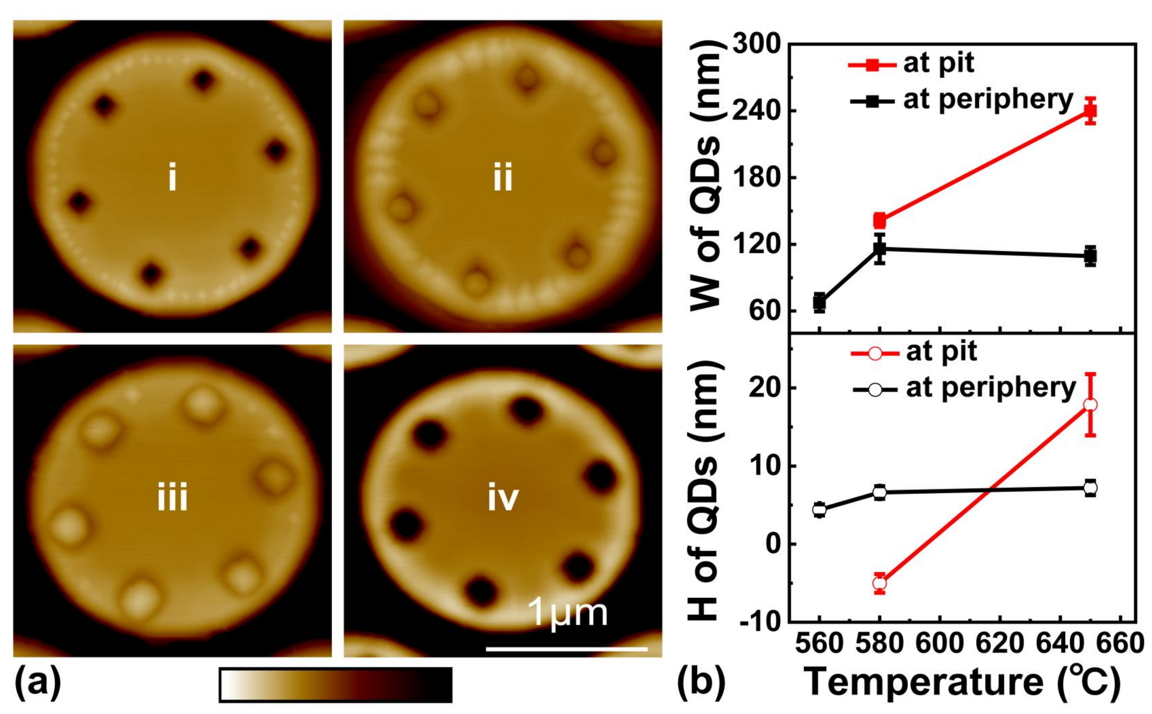


Fig 4. (a) AFM images of Ge QDs at different growth temperature. The graph as pit is too large is shown in (iv). (b) The dependence of mean QDs size on the growth temperature.
Large QDs are formed at pits and there are almost no redundant QDs at periphery in (iii).

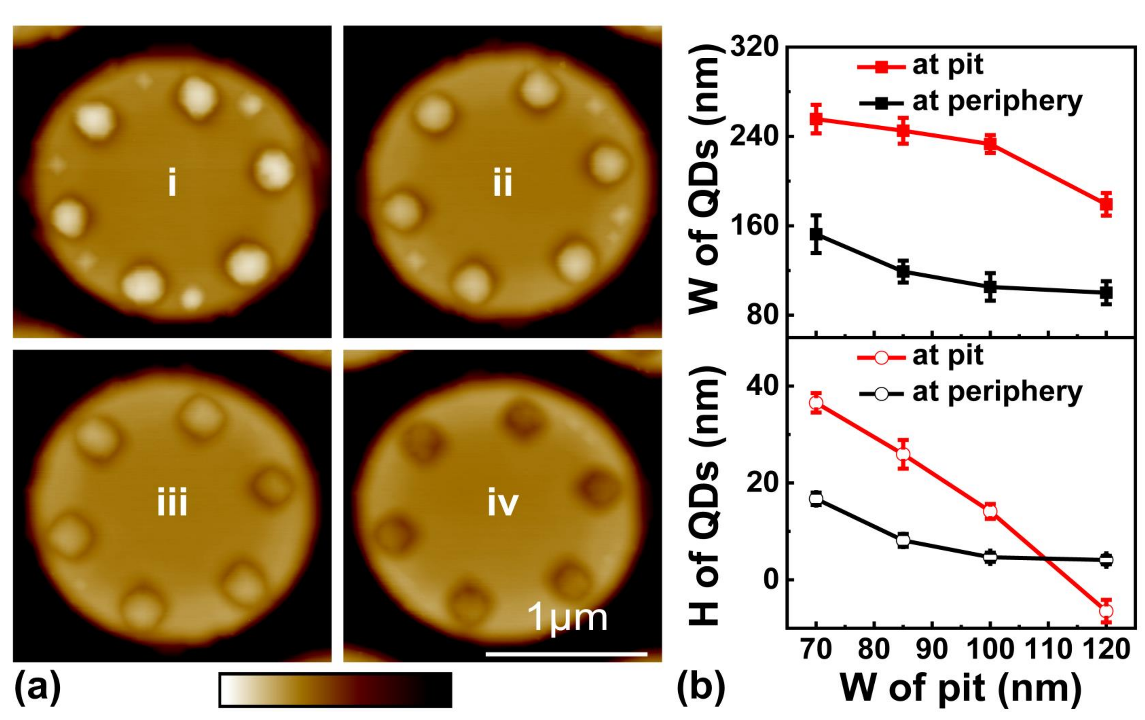


Fig 5. (a) AFM images of Ge QDs on the pillars with site-controlled pits of different diameter. (b) The dependence of mean QDs size on the width of pit.
The sizes of Ge QDs decrease obviously and the islands at periphery gradually disappear.

V. The Surface chemical potential model

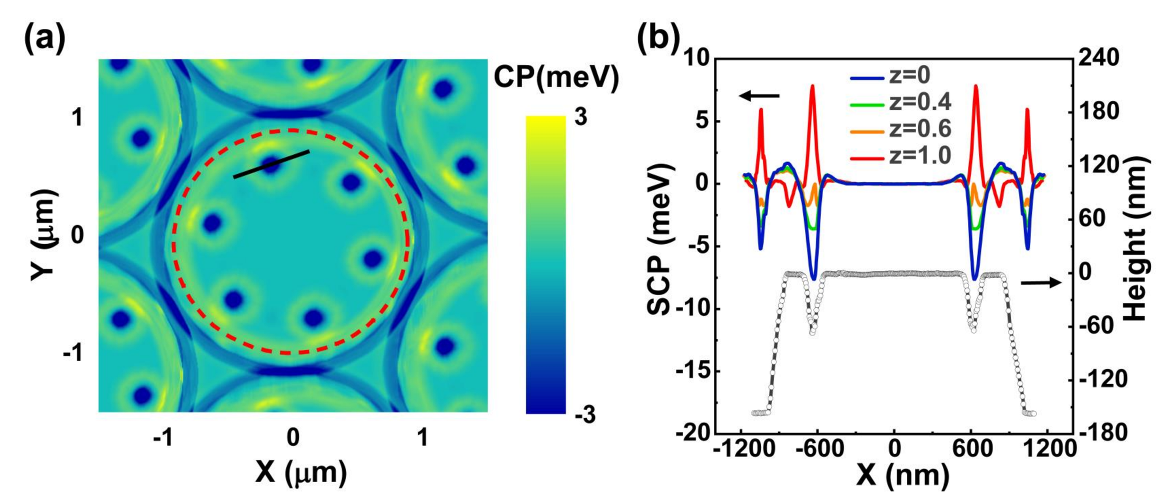


Fig 6. (a) The SCP map of micropillars before growth. The red dashed circle represents the edge of the pillar. (b) A series of SCP sections with different thickness of deposited Ge and corresponding surface profile.
Surface energy dominates in the outset. As the Ge increases, the strain energy is important.

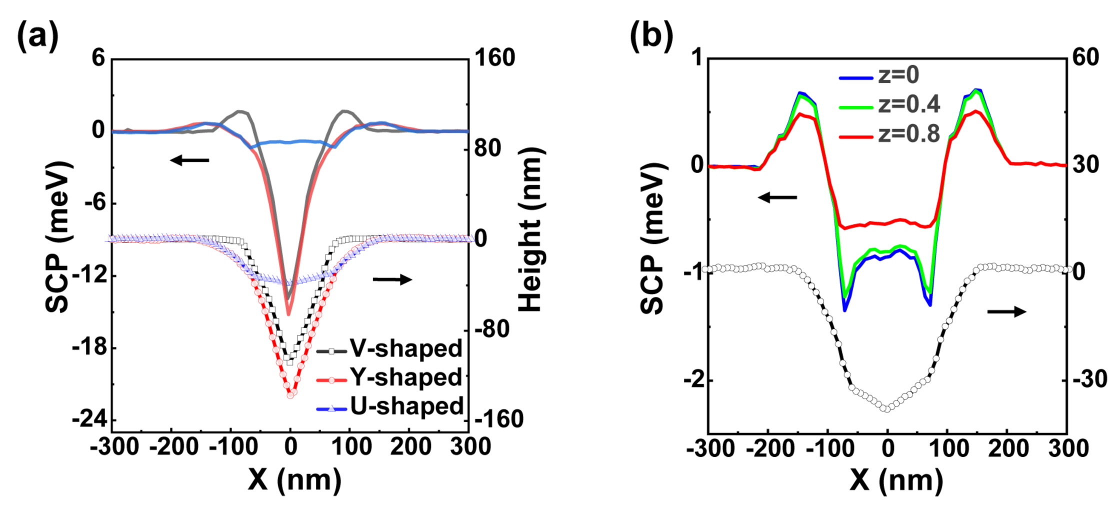


Fig 7. (a) The dependence between SCP around pits and the shape of pits. The black solid line in Fig 6(a) shows the cross-section. (b) The variation of SCP around a U-shaped pit and surface profile.
The barrier heights at the periphery of pits with diverse shapes are also different.

VI. The spacial coupling

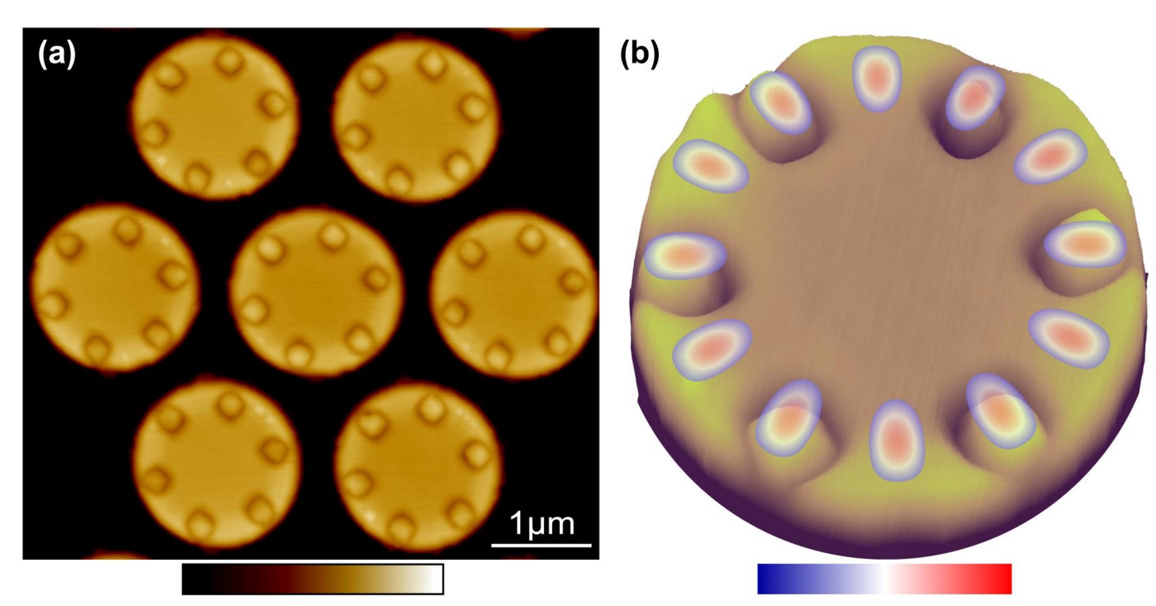


Fig 8. (a) The AFM image for an array of hexagonally arranged micropillars on a large scale. (b) The normalized light field distribution for WGM (TE1,6) at 1.55 μm with the 3D-AFM image of a microdisk.
The spatial matching of QDs and cavity mode of microdisks is achieved.

[1] F. P. García, Science 373, 640 (2021).
[2] Magdalena, ACS Photonics 4, 665 (2017).
[3] N. Zhang, Adv. Photonics Res. 2200100 (2022).

VII. Conclusion

1. With the help of pre-patterned substrate, the site-controlled growth of self-assembled Ge QDs in SiGe microcavities is achieved.
2. The size and distribution of QDs can be intentionally tailored by adjusting several important parameters such as the total amount of deposited Ge, the growth temperature and the width of pit.
3. Further optimizing the growth conditions, QDs are controlled to be distributed almost exclusively at pits and the pits are exactly located at the field antinodes of corresponding cavity mode.
4. The internal mechanism of the mandatory addressability for Ge QDs is revealed by taking into account the evolution of surface chemical potential distribution on Si micropillars.