Patterned Epitaxial Growth of Ge nanostructures

J. H. G. Owen, J. Ballard, W. Owen, J. N. Randall and J. R. Von Ehr
Zyvex Labs LLC, 1301 N. Plano Rd, Richardson, TX 75081, USA.

D. Dick, J.-F. Veyan and Y. J. Chabal
Materials Science and Engineering Department, University of Texas at Dallas, 800 W. Campbell Road, Richardson, Texas 75080, United States

jowen@zyvexlabs.com

The Ge/Si(001) heteroepitaxial system forms self-assembled quantum dots, with potential applications in optoelectronics. However, due to their self-assembled nature, there is no way to control their location and relative spacing on the surface. Various attempts have been made, for example by growth through holes in a Si oxide film used as a mask[1]. We are developing the use of STM-based H depassivation lithography (HDL), as in Fig. 1a, which can write patterns with atomic precision over position and dimensions. In previous work,[2] we demonstrated the process of Patterned Atomic Layer Epitaxy (P-ALE) of Si and Ge on Si(001). With repeated cycling of disilane exposure and HDL, multilayer epitaxial structures were formed, confined to the patterned area. However, this process is very slow, as it requires 3 pattern/dose cycles per ML.

We found using FT-IR spectroscopy that the temperature at which H desorbs from digermane fragments on Ge(001) is at or below the limiting temperature at which the passive H/Si background remains stable, ca. 300°C. Testing this prediction, we have developed a hybrid patterned epitaxial growth process with a substantial increase in growth rate over the previously-described P-ALE process. First, we grow a Ge seed, comprising 2-3 ML, within a patterned area on the Si(001):H substrate using P-ALE at a substrate temperature of 270-300°C, as shown in Fig.1b. The seed is then simply exposed to a steady Ge_2H_6 exposure for 1h without further depassivation steps, resulting in the growth of a substantially taller structure (2.5 nm vs. 0.5nm), as shown in Fig.1c, while maintaining conformality to the original depassivated area. The effect of the substrate temperature and the digermane flux on the growth rate and island morphology will be discussed.

---

[1] *Nanometer-scale Ge selective growth on Si(001) using ultrathin SiO_2 film* Y. Nitta, M. Shibata, K. Fujita, and M. Ichikawa *Surf. Sci. Lett.* **462** L587 - L593 (2000) DOI: 10.1016/S0039-6028(00)00547-1

[2] *Patterned Atomic Layer Epitaxy of Si / Si(001):H* J. H. G. Owen, J. Ballard, J. N. Randall, J. Alexander, and J. R. Von Ehr *J. Vac. Sci. Technol.* B **29** 06F201 (2011) DOI: 10.1116/1.3628673

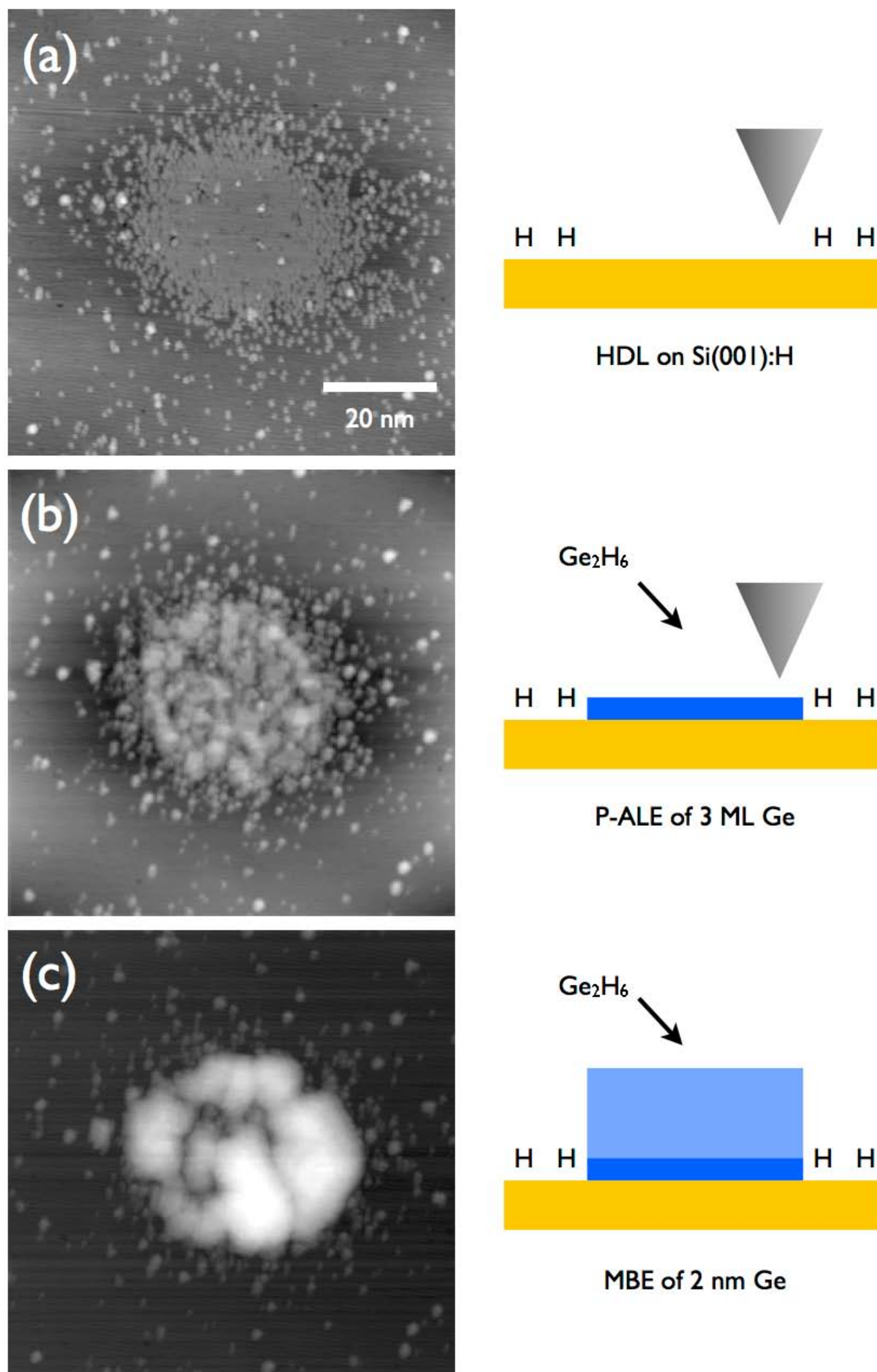

Figure 1: (a): Initial patterned area of Si(001):H surface (H depassivation lithography 8 V, 1 nA, 0.5 mC/cm). Substrate temperature is 270-300°C.
(b): 3 ML Ge island grown by 9 cycles of P-ALE, comprising 10s pulses of a saturation dose of Ge_2H_6 followed by H depassivation lithography. Height is ca. 3 ML or 0.5 nm. (c): The same Ge island, after exposure to 2 x 10^{-6} Torr Ge_2H_6 for 1 hr, without further lithography. Peak height is now 2.5 nm.