



Replica of “The red armchair” by Pablo Picasso in porous silicon Bragg reflectors

Fig. 1. An optical reflection image of a $350\text{ }\mu\text{m} \times 500\text{ }\mu\text{m}$ region irradiated with different doses of 2 MeV protons. The wafer was etched with an alternating high/low current density. The etch rate was progressively slowed by larger irradiation doses, resulting in thinner porous layers that reflect shorter incident wavelengths^[4]. Each dose produced a different reflected colour when illuminated with white light, with red/orange colours corresponding to areas of lowest dose.

100µm

Ee Jin Teo

Artistic Scientific Images

Recently, we have seen rapid progress in the area of photonics and photonic circuits to meet the ever increasing demand for bandwidth and higher communication speeds.

The key technology that will enable rapid progress to be achieved is the development and improvement of photonic integrated circuits (PIC). As is the case in electronics, silicon will most likely be the material of choice for the fabrication of PICs because it has a high transparency in the near infrared optical spectrum. Silicon-based photonics has additional advantages because the existing silicon-processing infrastructure can be used and there is considerable knowledge already available in the silicon microelectronics industry. The goal is to eventually achieve the monolithic integration of photonic devices and electronic devices on a single silicon microchip.



“Ancient of Days” From classical art to quantum art

Fig. 2. A $500\ \mu\text{m} \times 500\ \mu\text{m}$ photoluminescence image of “Ancient of Days” was created in porous silicon using focused helium beam writing and subsequent electrochemical etching^[1]. Due to the quantum confinement effect, visible light emission is observed from the nano-sized silicon skeleton left behind after etching. The ion irradiation reduces the etch rate of porous silicon, and increases the size of the silicon nanocrystals formed. This results in a red-shift of the photoluminescence of the porous silicon with higher dose upon ultraviolet (UV) excitation. Using the high resolution capability of focused ion beam writing, we are able to transform William Blake’s piece of classical art into an image consisting of finely tuned nanocrystals, which we call ‘quantum art’. Reprinted with permission from ^[1].

Porous silicon possesses unique optical properties that make it potentially useful for photonics applications. The material consists of silicon nanocrystals which can emit visible photoluminescence due to the quantum confinement effect. It is also relatively easy to control the porosity, thickness and refractive index of the material by changing the etching current density used during processing. By varying the etch current density, a sequence of porous layers with alternating high and low refractive index can be easily created to produce a Bragg reflector. My research is focused on using ion beam and electrochemical etching techniques to produce patterned porous silicon light emitters and waveguides with Bragg claddings. We demonstrate the ability to control the light emission and reflectivity of porous silicon using ion beam irradiation in a variety of shapes and patterns with micrometer spatial resolution. The best

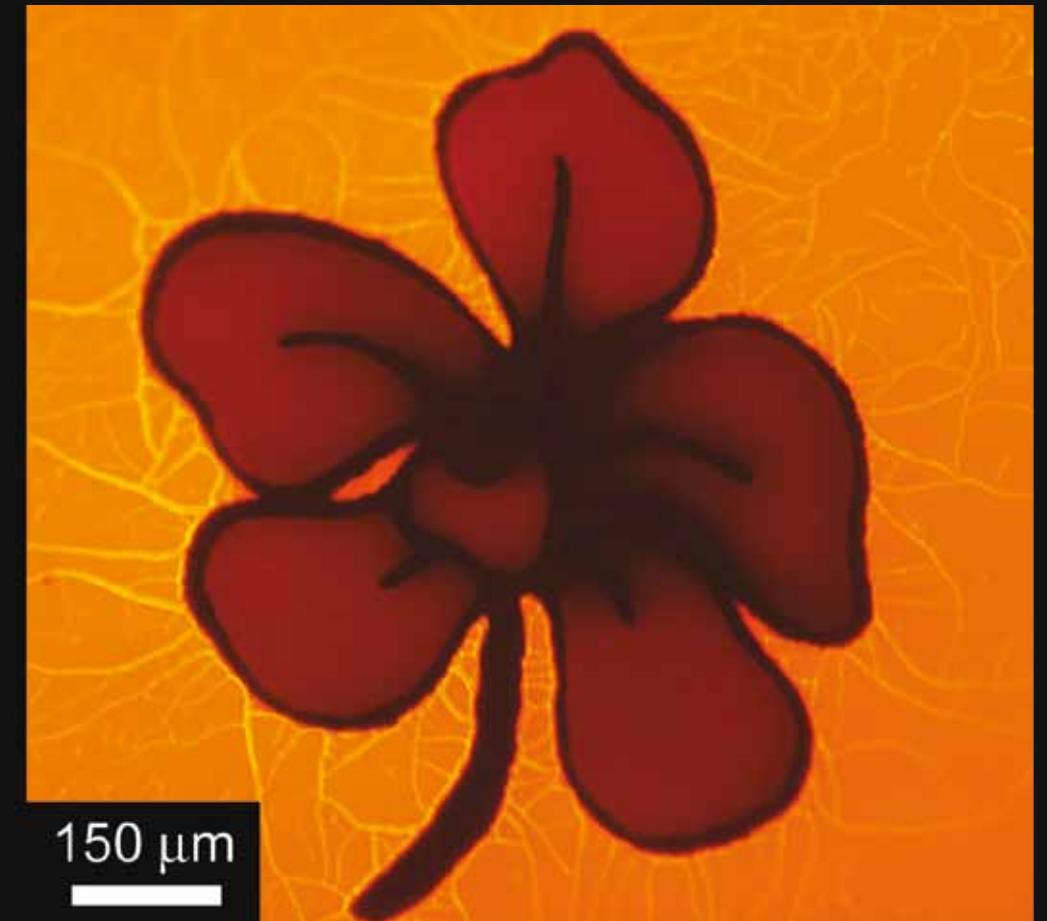
way to capture attention and demonstrate this is to create images by famous artists like Picasso in “The red armchair”, William Blake in “Ancient of days” and Matisse in “The Dance”. This work showcases the ability to integrate light emitters and low loss waveguides with Bragg claddings onto a single silicon chip.

We have also demonstrated a novel way of fabricating multilevel structures in silicon. It allows us to have three-dimensional control of the optical confinement needed for various photonics applications, such as free-standing waveguides and taper fabrication. Since Stonehenge is an icon people know of, replicating this structure is a good way of demonstrating our technology and showcases the unique capabilities of our technique.



Glowing micro-dragons

Fig. 3. Photoluminescence images of dragons formed by proton beam writing and electrochemical etching. Under UV excitation, the regions irradiated by ions show higher red emission compared to the un-irradiated regions^[2]. Reprinted with permission from ^[1].



The Singapore Orchid

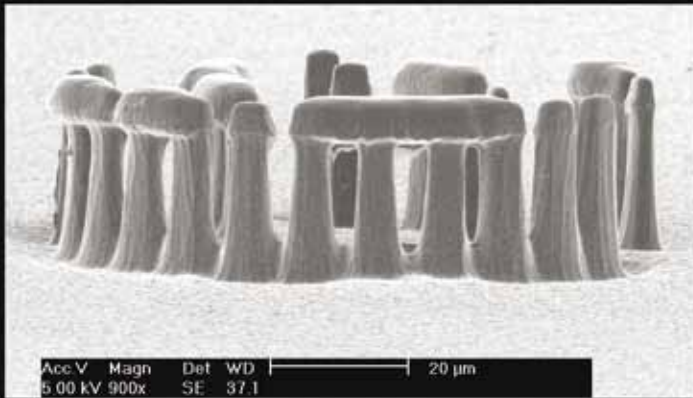
Fig. 4. A photoluminescence image of a miniature Singapore orchid patterned in light emitting porous silicon using helium beam writing and electrochemical etching. Under UV excitation, it glows red against a yellow background. Reprinted with permission from ^[3].



100 μm

Replica of “The Dance” by Henri Matisse in porous silicon Bragg reflectors

Fig. 5. Similar technique as described in Figure 4. This is an optical reflection image of a $500\ \mu\text{m} \times 400\ \mu\text{m}$ replica of “The Dance” by Henri Matisse in porous silicon Bragg reflectors patterned by proton beam irradiation.



Miniature Reproduction of Stonehenge in silicon

Fig. 6. Measuring $80\ \mu\text{m}$ in diameter, we have fabricated the world’s smallest replica of Stonehenge in bulk silicon using double-energy proton beam irradiation and electrochemical etching. Ion irradiation is used to create localized regions of higher resistivity which acts as an etch stop during subsequent electrochemical etching. Lower energy proton irradiation is used to create the shallow top layer, while higher energy irradiation is used to create the longer pillars. Prolonged etching results in the undercutting of the shallow top layer, supported only by the longer pillars^[6,7]. Reprinted with permission from^[5].



Chinese calligraphy written in porous silicon Bragg reflectors

Fig. 7. An old Chinese saying “Shi Zai Ren Wei”, which can be loosely translated to “anything can be achieved with human effort”, is inscribed by a femtosecond laser on porous silicon Bragg reflectors. The localized heating caused by the laser writing process changes the porous silicon to transparent silicon dioxide. Under white light illumination, the optical images of the patterned characters show different reflection wavelengths in the bright (top) and dark (bottom) field. Picture by Ee Jin Teo and Yuanjun Yan.

Acknowledgement

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