Low Cost Silicon-based Semiconductor Device Manufacturing

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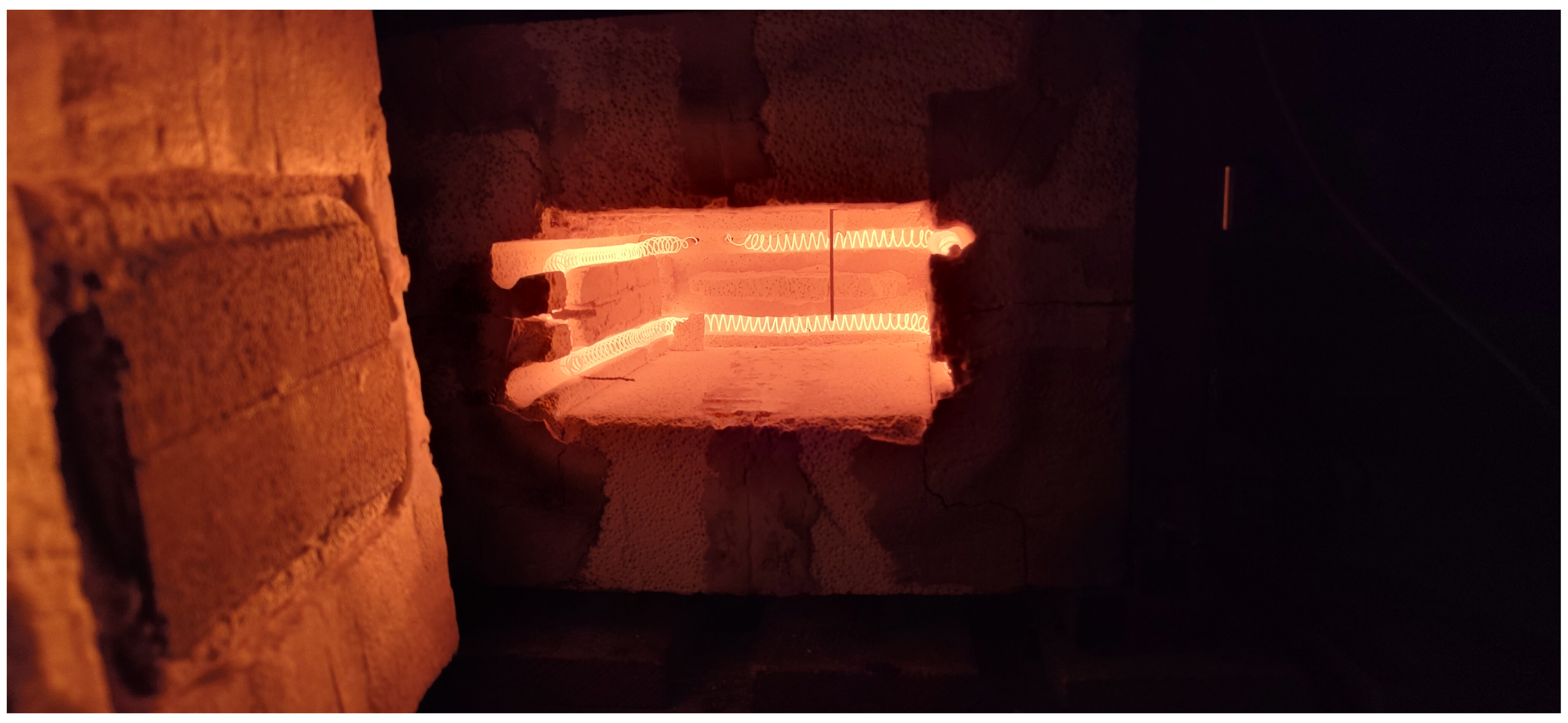
Motive

High costs of acquiring and maintaining specialized and high quality equipment for semiconductor manufacturing poses a challenge for individuals to experiment and learn about the technology. **We present cost-effective methods for engineering equipment and complete process for silicon-based semiconductor device manufacturing and testing.** We focused on obtaining results in an easily affordable environments by sacrificing economic scaling and quality of the manufactured devices. **We aim to pave the way for students and enthusiasts interested in semiconductor manufacturing.**

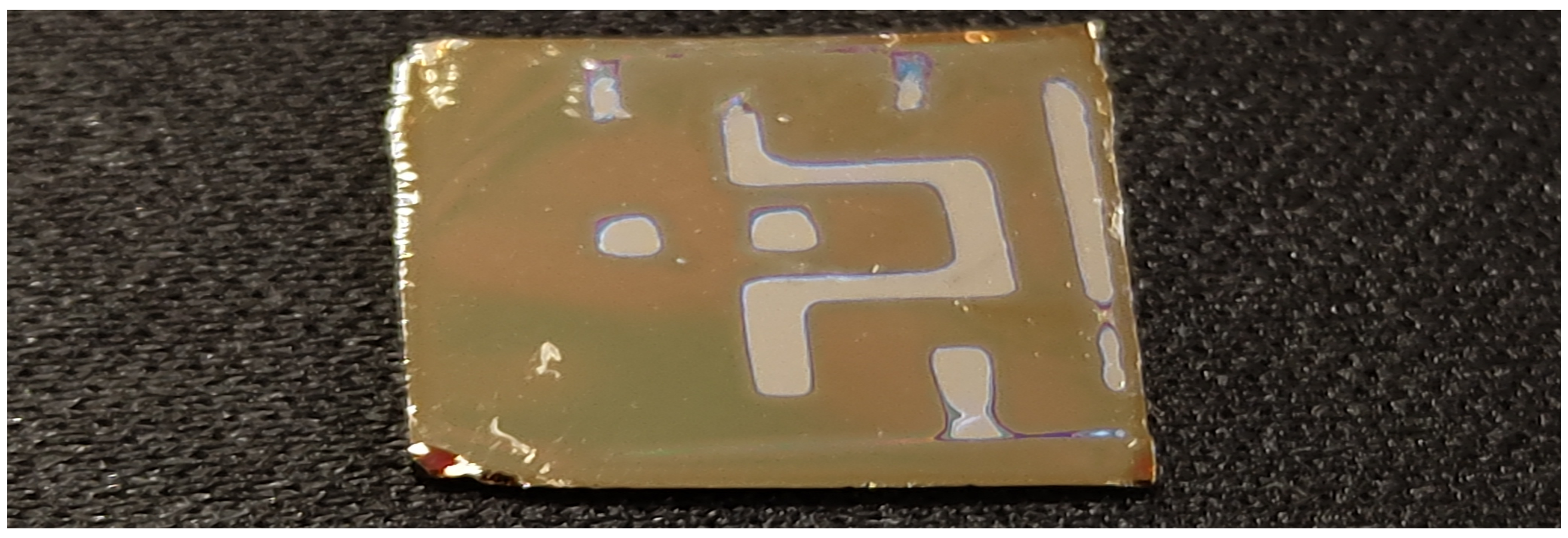
High temperature furnace

Electric furnace that can reach up to **1200°C**. It is used for **oxide growth** and **diffusion doping**. It is built using the firebricks and resistance wire, **wirelessly controlled** using Raspberry Pi Pico W microcontroller[1]. The temperature is measured with pt100 temperature sensor. It has a **water pump** mounted at the top with the quartz tube going inside the furnace, allowing **wet oxidation** of the wafers. Type K thermocouple is used to measure the temperature inside the furnace. The microcontroller can control the rate of heating, automatic temperature steering and water pumping. We provide an **open source firmware and PCB design**[2].



Photolithography

We do **maskless photolithography**, using **DLP projector** with the **modified optics** to obtain a sharp image on the surface of the wafer. We pattern the wafer using **AZ 1512 HS photoresist**[3] with **AZ 351 B developer**[4] from MicroChemicals, spin coated on top of it. The projector is mounted vertically, aiming at the flat bed underneath where the wafer is positioned. Desired **pattern is prepared in JPEG format** using GIMP[5] and displayed with the DLP using a PC. DLP projectors are based on **mercury vapor lamp**, which emit UV light and **DMD (digital micromirror device) chip**[6]. We use combination of white and black pixels in the image to select which part of the wafer should be exposed to UV. There is a 3D-printed shutter connected to the electric motor driven by Raspberry Pi Pico W[1], which can be used to expose the wafer for the desired duration, controlling the amount of UV that hits the photoresist. We provide the microcontroller **firmware as an open source software**[2].

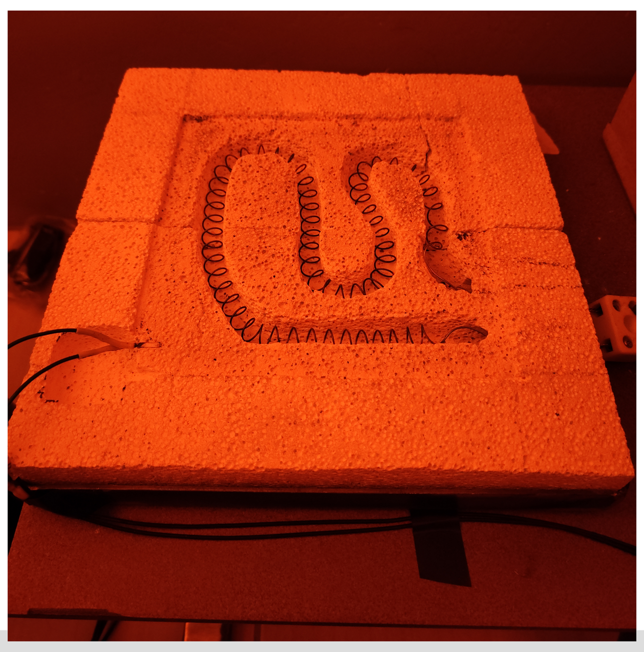


Contacts

Contacts are done using silver epoxy and copper wires. The other end of the wire can then make a direct contact with the probe or soldered into a prototyping board or PCB for testing.

Hotplate

Electric hotplate that can reach up to **400°C**. Based on the firebricks and resistance wire. Used for soft and post-exposure bake of photoresist, synthesis of tetraethyl orthosilicate based Spin-On-Dopant and it's predeposition step before diffusion doping in the furnace. Raspberry Pi Pico W microcontroller[1] is used for wireless access, controlling rate of heating and automatic temperature steering. We provide the microcontroller **firmware as an open source software**[2].



Doping

We propose a modified process to the one described in Fangsuwannarak et Al. 2019 [7]. It yields a less, but sufficiently viscous dopant and significantly **extends its shelf life at room temperature**. We spin coat the dopant on the wafer, do pre deposition on hot plate and thermal diffusion in the furnace. This creates N-doped wells and phosphosilicate glass (PSG). The PSG is stripped using $NH_4F \cdot HF$ solution dissolved in DI water. For **selective doping**, we use thick ($\sim$500nm) thermally grown SiO_2, that stops spin coated SOD from penetrating too far into the wafer. We control for rate of doping by doing a **double-oxidation** process, which grows two layers of SiO_2, one, for completely stopping the doping $\sim$500nm and another in a range of 30-100nm, which acts as a doping limiter and not a complete stopper.

Spin coating

We successfully used a 3000 RPM, 12V **computer fan** to manufacture solar cells and NPN MOSFET devices with a double-sided tape on which the wafer is placed. The solution, while very cheap and simple, but is not very convenient. The tape has to be replaced frequently, and contaminates the back of the wafer. For this reason, we **designed and 3D-printed** a **rotating bed** with an opening in the middle and a chamber. The bed is connected to the **BLDC motor** that can spin the bed to up to **4000 RPM**. We use **infrared light source and detector**, connected to the Raspberry Pi Pico microcontroller[1], forming a **feedback** and allowing us to **control the rotating speed of the bed**. The opening in the bed is connected through a hose to the modified **vacuum cleaner** that sucks the wafer down to the bed.

References

[1] *Raspberry Pi Pico W*. url: https://www.raspberrypi.com/documentation/microcontrollers/raspberry-pi-pico.html.
[2] *Lab firmware*. url: https://github.com/secmeant/pico-furnace.
[3] *AZ 1512 HS Photoresist - MicroChemicals*. url: https://www.microchemicals.com/en/AZ-1512-HS-Photoresist-3.785-l/1A001512.
[4] *AZ 351 B Developer*. url: https://www.microchemicals.com/en/AZ-351-B-Developer-5.00-l/1000351.
[5] *GNU Image Manipulation Program (GIMP)*. url: https://www.gimp.org/.
[6] *Texas Instruments DLP® technology*. url: https://www.ti.com/dlp-chip/overview.html.
[7] Thipwan Fangsuwannarak, Supanut Laohawiroj, and Kamonchanok Mekmork. "Synthesis of Phosphorus Solution for n + Si Selective Emitter Solar Cell by Spin on Doping". In: *E3S Web of Conferences* 122 (Jan. 2019), p. 02006. doi: 10.1051/e3sconf/201912202006.

Testing & results

We were able to make various devices, including **resistors**, **solar cells**, **capacitors** and **MOSFETs**.
It's important to note, that the obtained results are **significantly worse than their commercial equivalents** and that they are **primarily useable as a learning ground and experimentation**, with the main advantage of relatively **easy access** to the required tooling and components used to build the whole lab.

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