Single wavelength hybrid silicon lasers

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A method of integrating lasers with a silicon photonic chip may provide ultrafast optical data links.

Today’s electrical computer connections are reaching their limits, affecting both computer performance and connectivity to the outside world by restricting Internet speed. Data links that operate at 10Gb/s, spanning over 1m, are barely possible electrically whereas optical links have the potential to provide more than 100 times this bandwidth. ‘Silicon photonics’ are optical devices manufactured using the high volume manufacturing techniques of the silicon micro-electronics industry. They have the potential to enable low-cost, high-data-rate optical communication for computers.

High bandwidth (\(\gg 40\)Gb/s) optical links typically use wavelength division multiplexing, in which each wavelength of light acts as a separate data channel to produce high aggregate bandwidth links. Figure 1 shows a schematic diagram of a high data-rate optical chip containing 25 lasers each emitting a different single wavelengths. Silicon modulators encode 40Gb/s of data onto the light from these lasers before the different colors are combined by a wavelength multiplexer into a single optical fiber that provides a data rate of 1Tb/s. A key challenge for silicon photonics is how to integrate such an array of single wavelength lasers and a silicon photonic chip.

Because light emission from silicon is very inefficient, silicon cannot be used to produce the lasers needed for optical links. As a result, semiconductors made from a combination of elements from groups III and V of the periodic table, are typically used for laser sources. There have been many attempts to integrate such lasers with silicon photonic dies, including ‘flip chip bonding’, in which prefabricated laser die are passively aligned to the silicon dies using mechanical stops before being soldered into place. Alternatively, surface-corrugated gratings can be patterned on the top surface of the silicon waveguide. These allow coupling of light from vertical to normal incidence for photodiodes and perhaps vertical-cavity surface-emitting lasers. The drawback with these approaches is that they are slow and costly because each laser must be individually aligned before being attached.

We have developed a hybrid silicon device technology, in which an unpatterned III-V die is molecularly bonded to a silicon waveguide before being processed into a laser. Using an unpatterned die has the key advantage that critical alignment is unnecessary. After bonding, alignment marks on the silicon are used to make the III-V die into lasers self-aligned with silicon waveguides. We call these ‘hybrid silicon lasers’ because the optical mode overlaps with different materials: it is guided by the silicon waveguide but obtains gain from the III-V multiple quantum wells (MQWs). The emission wavelength of these lasers is determined by gratings patterned in the silicon, which are lithographically aligned to the multiplexer and other silicon components. A single die can be used for many hybrid silicon lasers, as shown in Figure 2. In these research devices, for example, a single bonded 8 × 8mm\(^2\) indium phosphide die can produce 300 lasers.

![Figure 1. Laser light is generated, modulated, then combined on terabit photonic chip.](image-url)
We have demonstrated a variety of different single wavelength lasers with this platform, including both distributed feedback lasers and distributed Bragg reflector (DBR) lasers. We also expanded the III-V processing to include quantum well intermixing, which allows us to fabricate tunable DBR lasers. Here we will focus on the DBR lasers.

Figure 3 shows a schematic diagram of the laser and a top down microscope image of an array of these devices. The gain section of these lasers is comprised of aluminium gallium indium arsenide MQWs bonded to the silicon waveguide. We use lateral tapered mode converters to couple the light from this section to the passive silicon waveguides containing the Bragg gratings with minimal optical loss. These gratings act as the laser end mirrors and determine the wavelength of emitted light.

Outside the laser cavity the light is guided through passive silicon waveguides to hybrid silicon photodiodes to measure the laser performance. One set of detectors can be seen on the left hand side of the optical micrograph.

Figure 4 shows the output power of the laser as a function of bias current for different ambient temperatures. The dips in this plot are caused by mode-hops when the laser jumps from one cavity to another due to device heating. The laser threshold is measured to be 65mA with a maximum output power from the front facet of 11mW and a differential quantum efficiency of 15%. The laser has a maximum operating temperature of 45°C.

The output spectrum of the laser is shown in Figure 5 at a bias of 200mA. This shows a single mode lasing with a wavelength of 1597.5nm and a side-mode suppression ratio greater than 50dB.

The hybrid silicon device technology is a promising way to integrate III-V lasers with silicon photonics. Here, we have presented single wavelength DBR lasers integrated with passive silicon waveguides and hybrid silicon detectors. So far, our results show that we can use gratings patterned in silicon to determine the laser wavelength. Our next steps focus on optimizing the laser performance, reducing the threshold current, and increasing the maximum operating temperature.

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Figure 5. Emission spectra of hybrid silicon DBR laser showing single wavelength operation.

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