Silicon-Integrated 850-nm Hybrid-Cavity VCSEL

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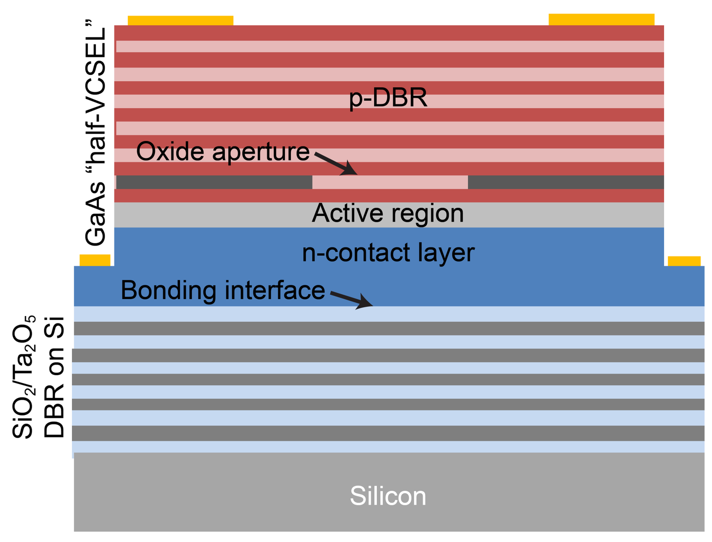
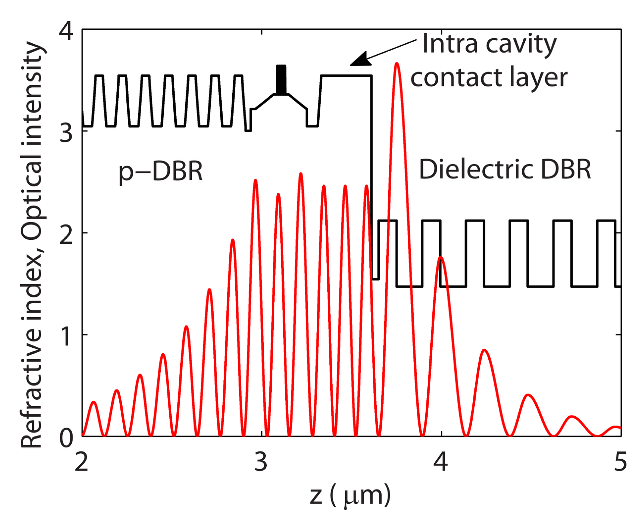
Introduction

Silicon photonics is a promising energy-efficient and cost-effective platform for optical integrated circuits. However, due to its indirect bandgap silicon cannot be used to produce effective light sources. An attractive solution to this is heterogeneous integration of the GaAs-based vertical-cavity surface-emitting laser (VCSEL) on silicon. The GaAs-based VCSEL has proven to be both high-speed and energy efficient, with data rates above 70 Gb/s [1] and less than 100 fJ/bit dissipated power up to 50 Gb/s [2].

By employing ultra-thin divinylsiloxane-bis-benzocyclobutene (DVS-BCB) adhesive bonding [3] a “half-VCSEL” with a gain region and a top distributed Bragg Reflector (DBR) has been attached to a dielectric DBR on silicon. This creates a hybrid cavity where the standing-wave optical field is extending into both the silicon and GaAs-based parts of the cavity [4].



Schematic cross-section

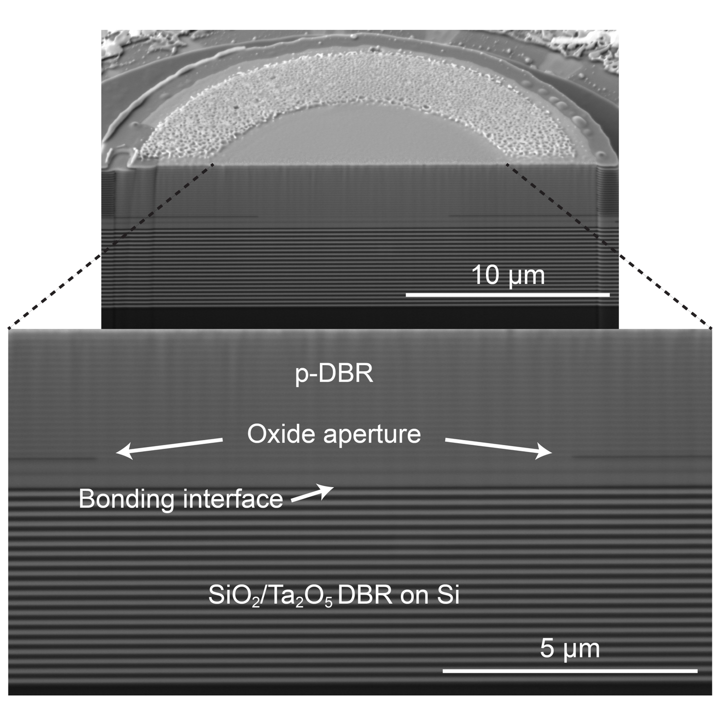


Simulated optical field in the cavity

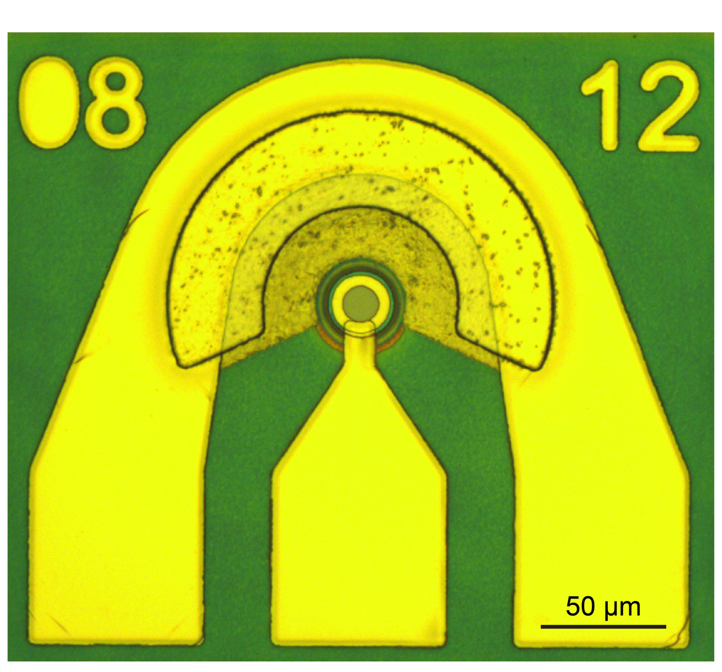
The hybrid-cavity may eventually enable light to be tapped off to an in-plane waveguide, e.g. using a high contrast grating (HCG) instead of the bottom DBR [5]. Replacing the whole bottom DBR with an HCG also gives the possibility to set the wavelength according to the grating parameters, enabling fabrication of multi-wavelength VCSEL arrays [6] that together with integrated wavelength multiplexers could form 850-nm wavelength division multiplexed (WDM) transmitters [4].

Processing

After bonding of the GaAs-based “half-VCSEL” epitaxial structure using the DVS-BCB adhesive bonding, the GaAs substrate was removed by mechanical thinning and wet etching followed by deposition of contacts, formation of oxide aperture, and planarization with benzocyclobutene (BCB) [4].



Scanning electron microscope (SEM) images of a focused ion beam (FIB) cross-section

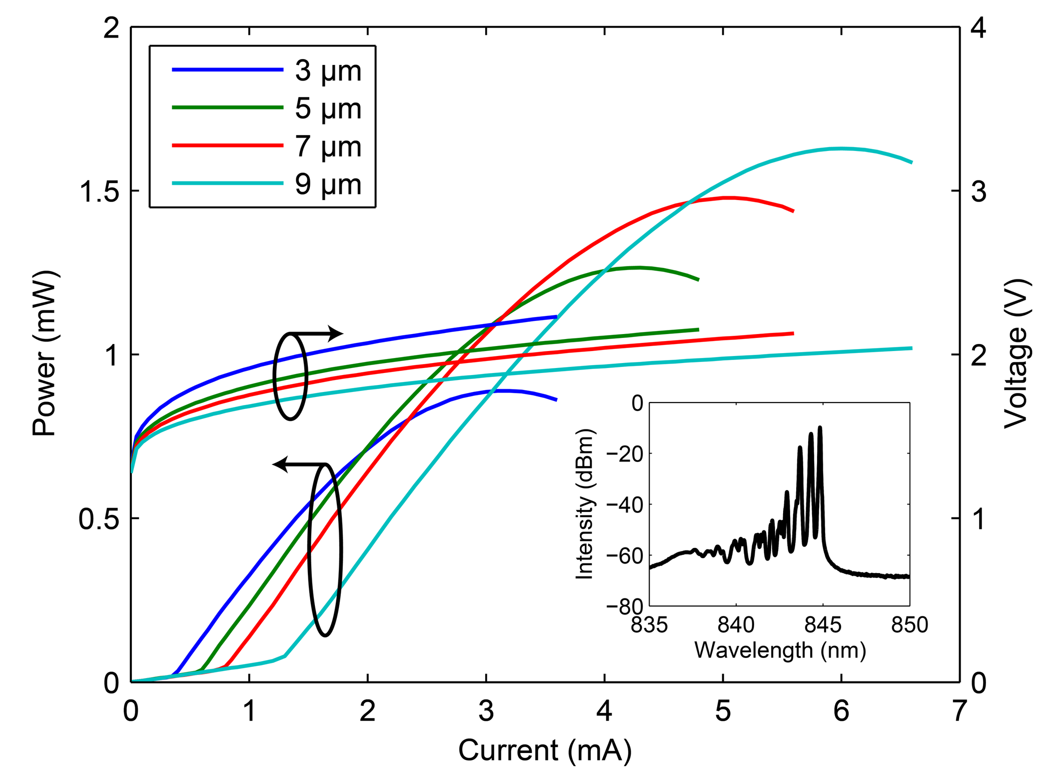


Microscope top image of the VCSEL with bondpads

Results

Light-current-voltage characteristics under continuous operation measured at 25°C

- Threshold currents: 0.3 mA to 1.2 mA (3 to 9 µm aperture VCSEL)
- Differential resistances: 50 Ω to 120 Ω (9 to 3 µm aperture VCSEL)
- Maximum output power: 1.6 mW (9 µm aperture VCSEL)
- Optical output wavelength: ~845 nm [4].



Light-current-voltage characteristics for hybrid-cavity VCSELs.
Inset: Spectrum of a 7 µm oxide aperture VCSEL at 3.0 mA bias.

Temperature dependence

- Light-current-voltage at different heat-sink temperatures:
  - Minimum threshold current at –16°C
  - Too small gain-to-resonance detuning, caused by a too thin DVS-BCB bonding layer.
  - The DVS-BCB bonding layer thickness should be increased by 20-40 nm.
- Thermal impedance at 25°C: 7.5 K/mW to 12.3 K/mW (9 to 3 µm aperture VCSEL)
  - ~3 times higher than ordinary VCSELs
  - Due to limited heat transport through the dielectric DBR to the Si substrate.
  - Explains the early thermal rollover of the output power.
  - Additional heat-spreader could be included in future design [4].

Conclusion

A silicon-integrated hybrid-cavity VCSEL with emission at 850 nm has been demonstrated by using DVS-BCB adhesive bonding. A 9 µm oxide aperture diameter VCSEL has a threshold current of 1.2 mA and a maximum output power of 1.6 mW at ~845 nm. The performance is currently limited by the too small gain-to-resonance detuning and the high thermal impedance.

References

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