

# A Stable Mid-IR, GaSb-Based Diode Laser Source for Cryogenic Target Layering at the Omega Laser Facility

## Introduction

Mid-IR, 3- to 3.5- $\mu\text{m}$  laser sources are important for various applications including gas sensing, spectral analysis, infrared illumination, countermeasures, medical diagnostics, and others. One particular application is the layering of cryogenic targets for inertial confinement fusion (ICF) implosions at the Omega Laser Facility.<sup>1</sup> Cryogenic targets are used to maximize the fuel density in ICF implosions. These targets consist of  $\sim 900\text{-}\mu\text{m}$ -diam microcapsules that are permeation filled with over 1000 atm of  $\text{D}_2$  (deuterium–deuterium) or DT (deuterium–tritium) gas and then cooled to  $\sim 18.7\text{ K}$  so that the gas is frozen and the capsules are no longer permeable. The frozen deuterium is then “layered” so that it is uniformly distributed around the inner surface of the capsule.<sup>2</sup>

The layering process relies on the target being in an isothermal environment—a layering sphere that is uniformly illuminated by 3- to 3.5- $\mu\text{m}$ , mid-IR light. The wavelength is tuned to the absorption peak in the fuel material (3160 nm with 22-nm FWHM for  $\text{D}_2$  targets). Since thicker regions of ice will have a longer path length, they absorb more radiation, so they

will be relatively hot spots; likewise thinner ice will absorb less radiation and be relatively cold spots. Fuel material will then sublime from the hotter regions and condense and refreeze on the thinner, colder regions, leading to a uniform distribution of fuel material (see Fig. 118.47). For this process to produce layers with the required uniformity, the temperature must be held very close to the material’s melting point. As a result, the mid-IR source’s output power and spectrum must be temporally stable to avoid overheating and melting the ice layer.

Currently a mid-IR optical parametric oscillator (OPO) is used to layer the targets.<sup>3</sup> Until recently, this was the only choice to achieve the required power of  $>100\text{ mW}$  in this wavelength range. The development of a mid-IR, GaSb-based quantum well diode that produces  $>100\text{ mW}$  of output power at room temperature<sup>4–6</sup> presents a new choice for the layering laser source.

This article presents, for the first time, the spectral and output-power stability studies of a GaSb-based diode laser operated at room temperature.

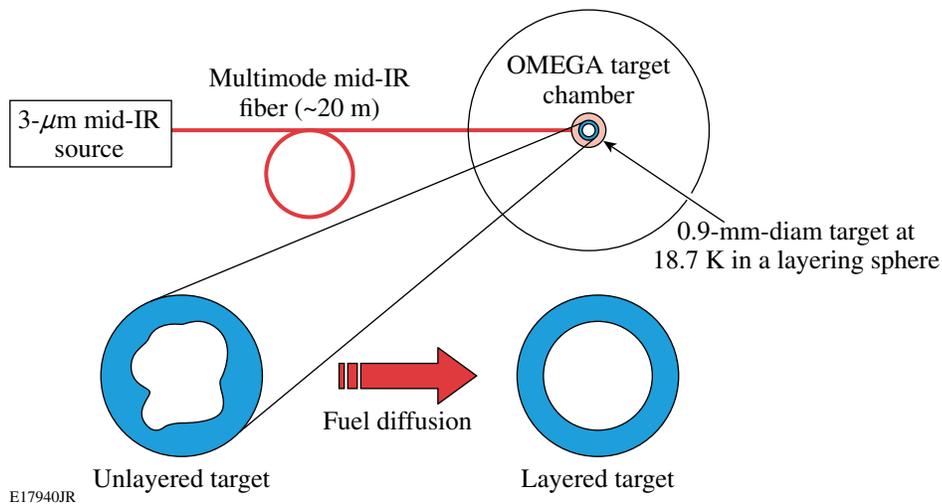


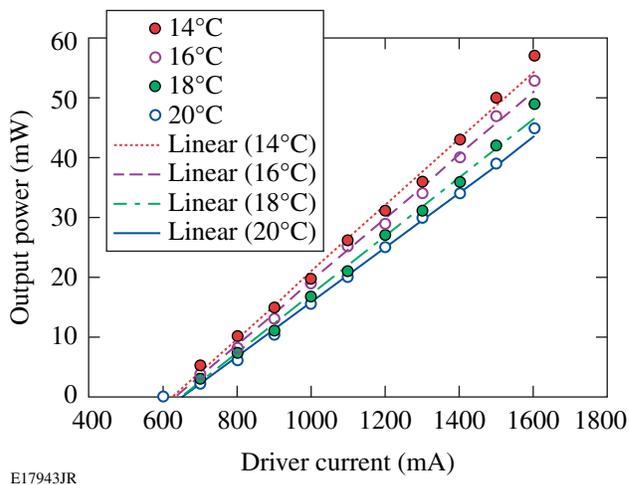
Figure 118.47  
Cryogenic target layering at the Omega Laser Facility requires a stable mid-IR light source.

### Diode Laser Growth and Assembly

Laser heterostructures were grown using the Veeco GEN-930 solid-source, molecular-beam-epitaxy system on Te-doped GaSb substrates. The band structure of a 3- $\mu\text{m}$  emitter is shown in Fig. 118.48. The cladding layers were 2.5- $\mu\text{m}$  and 1.5- $\mu\text{m}$ -wide  $\text{Al}_{0.6}\text{Ga}_{0.4}\text{As}_{0.05}\text{Sb}_{0.95}$  doped with Te ( $n$  side) and Be ( $p$  side), respectively. Graded-bandgap, heavily doped transition layers were introduced between the substrate and  $n$ -cladding and between the  $p$ -cladding and  $p$ -cap to assist carrier injection. The nominally undoped  $\text{Al}_{0.2}\text{In}_{0.2}\text{Ga}_{0.6}\text{As}_{0.02}\text{Sb}_{0.98}$  waveguide layer with a total thickness of about 800 nm contained two 12-nm-wide  $\text{In}_{0.54}\text{Ga}_{0.46}\text{As}_{0.23}\text{Sb}_{0.77}$  quantum wells (QW's) centered in the waveguide and spaced 40 nm apart. Thick waveguide and cladding layers were lattice matched to GaSb. The compressive strain in the QW's was about 1.8%. The wafer was processed into 100- $\mu\text{m}$ -wide, oxide-confined, gain-guided lasers. Two-mm-long neutral-reflection (NR  $\sim 30\%$ ) and high-reflection (HR  $\sim 95\%$ ) coated lasers were In soldered epi-side down onto Au-coated polished copper blocks (D-mount).

The 3000-nm laser diode assembled on a D-mount was placed on a thermo-electric cooler (TEC) mounted on a heat sink. A laser diode driver provided up to 3000-mA low-noise current with 1-mA resolution. The same driver provided TEC temperature control. The temperature of TEC cold plate was varied from 14°C to 20°C. Because this diode has not been tested for lifetime and temperature/current damage, the output power as measured by a FieldMaster GS power meter (Coherent) was limited to 50 mW, although a maximum output power of 130 mW at 17°C has been demonstrated.<sup>4</sup> Currently diode

lasers with output power  $>200$  mW can be safely operated. Figure 118.49 shows output-power versus driver-current dependencies at various temperatures. The output power slightly decreases as the temperature increases, as expected.

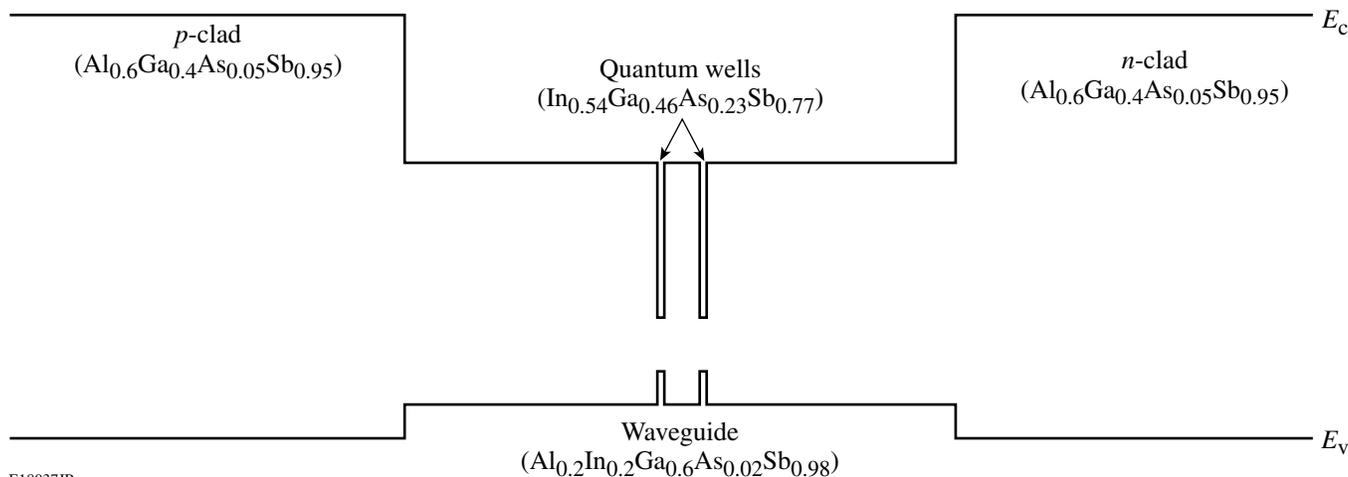


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Figure 118.49 The diode laser's output-power versus driver-current dependencies at different temperatures.

### Spectral and Output-Power Stability of a Diode Laser

The laser output-power's stability is excellent—less than 1% rms variations at 14°C over 1 h (see Fig. 118.50). The output power decreases as the temperature increases, and at the same time output-power variations are slightly higher at higher temperatures. The change in power variation increase is small but is well pronounced as shown in Fig. 118.51.

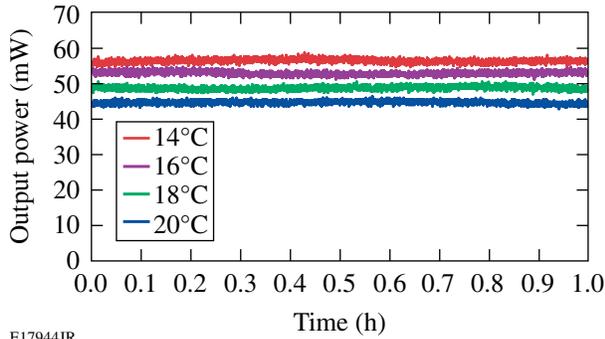


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Figure 118.48 Band structure of a 3- $\mu\text{m}$  emitter:  $E_c$ —the bottom of the conductive band;  $E_v$ —the top of the valence band.

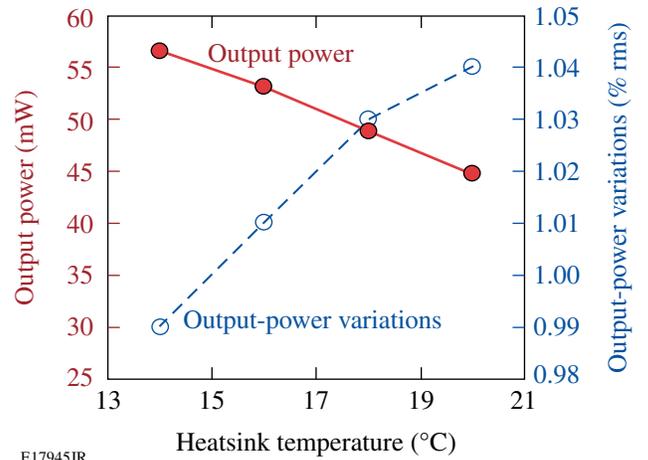
A Nicolet 6700 Fourier transform infrared (FTIR) spectrometer (Thermo Scientific) with a 0.5-nm spectral resolution around a 3000-nm wavelength was used for spectral measurements. The spectrometer was calibrated using 1152.3-nm and 3391.3-nm He-Ne laser spectral lines. The diode-laser output-spectrum's peak position and shape change dramatically

(over 20 nm) with current at constant TEC temperature [see Fig. 118.52(a)]. Once the current is set, the spectral shape is stable. To provide the required spectral and output-power stability



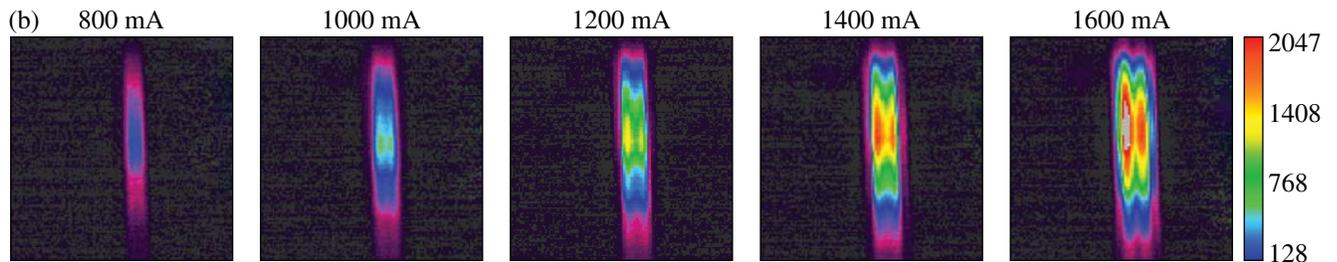
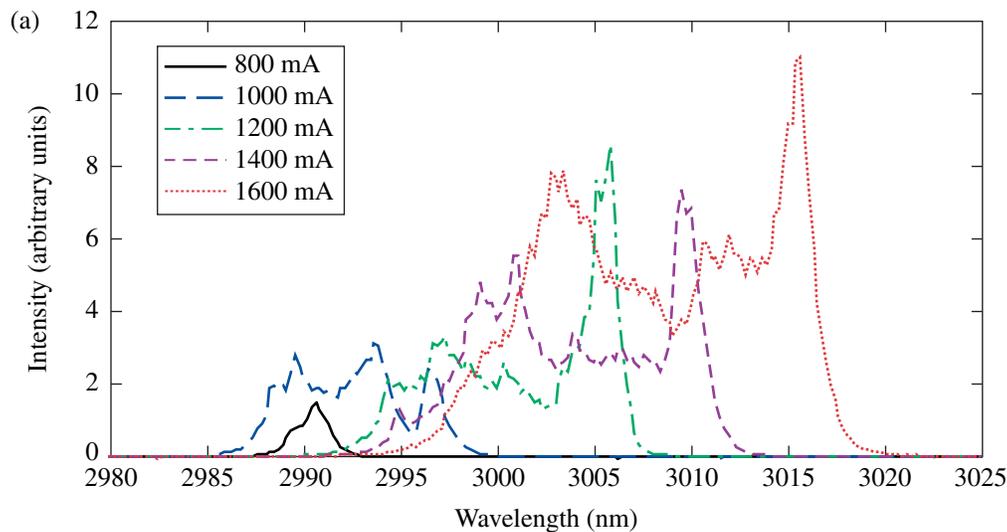
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Figure 118.50  
The diode laser's output-power stability is excellent (<1% rms variations at 14°C).



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Figure 118.51  
The diode laser's output power decreases and output-power variations increase with increasing temperature.



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Figure 118.52  
The diode laser's spectral shape and position change with (a) driver current as well as (b) beam profile. Data were taken at 14°C.

the diode laser's output power should be set for maximum and then the laser should be temperature tuned to a D<sub>2</sub>-ice absorption peak for this application. An external attenuator should be used to achieve the required level of target illumination.

The output beam's profile taken with a Pirocam III mid-IR camera (Spiricon) is not uniform along the diode output stripe and changes slightly with current [Fig. 118.52(b)]. The output divergence is typical for diode lasers and is  $\sim 65^\circ$  along the fast axis and  $\sim 20^\circ$  along the slow axis. Two ways of delivering radiation to a layering sphere are considered: using multimode mid-IR delivery fiber or mounting the diode laser directly on a layering sphere. In both cases the diode laser-beam profile quality will not affect the layering process.

The spectral stability of the diode laser over time was measured at various temperatures. Figure 118.53 shows four groups of spectra taken at 1600-mA current and various temperatures. Each group contains five spectra taken at 15-min intervals, i.e., over a 1-h period. At 14°C, the spectrum consists of two peaks with approximately equal intensities. The left peak intensity decreases and its stability becomes lower as the temperature increases. The stability of the left peak at 20°C is low due to the fact that it lases close to the threshold. This explains the lower output-power stability for this particular diode at higher temperatures. At the same time, the important criterion can be drawn for diode-laser selection for cryogenic target layering: a diode laser that is temperature tuned to the required wavelength must have a smooth and compact spectrum without low-intensity parts. The spectral nonuniformities of the laser

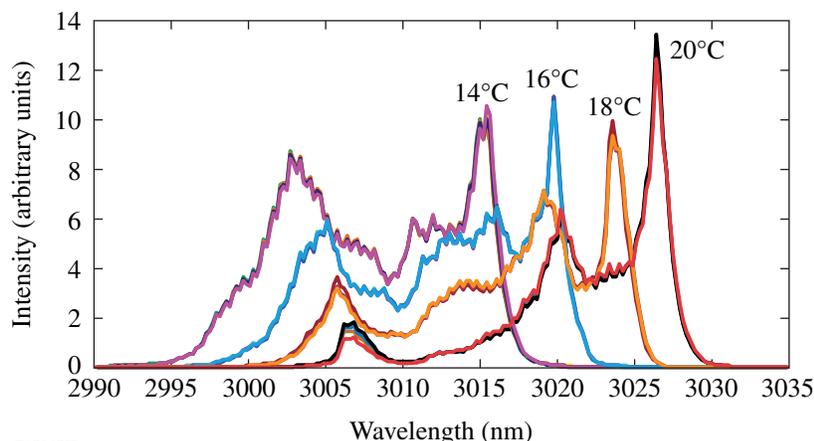
diode output can be associated with lateral fluctuation of the quantum-well parameters across the wafer, owing to a non-optimized growth regime of the quinary InAlGaAsSb barrier alloy used in the laser heterostructure to improve hole localization in the active region. It was shown that other diode-fabrication batches with an optimized growth regime result in lasers that have smooth and compact spectra. This criterion can be met by the careful selection of diode lasers from different batches.

### Conclusion and Future Research

We have studied the spectral and output-power stability of a 3- $\mu\text{m}$ -wavelength mid-IR diode laser and demonstrated the highly stable operation of a diode laser at up to  $>50$  mW of output power with  $<1\%$  rms variations at 1600-mA current and 14°C TEC temperature. It has been shown that spectral shape can affect the output-power stability. Future research will consist of building diode lasers that can be tuned to the target's ice absorption band (3160 nm) with a smooth and compact spectrum at the required wavelength. Highly efficient multimode, mid-IR fiber launching will be considered for delivering the radiation to a layering sphere, or the diode laser may be directly mounted on it.

### ACKNOWLEDGMENT

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Figure 118.53

The diode laser's spectral stability decreases with an increase of temperature.

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