A stable mid-IR, GaSb-based diode laser source for the cryogenic target layering at the Omega Laser Facility

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Abstract: A stable 3-μm-wavelength, GaSb-based diode operated at room temperature has been investigated as a potential laser source for cryogenic target layering at the Omega Laser Facility for inertial confinement fusion (ICF) experiments. More than 50 mW of output power has been achieved at 14°C with high spectral and output-power stability.

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OCIS codes: (140.2020) Diode lasers; (140.3070) Infrared and far-infrared lasers.

References and links

1. Introduction

Mid-IR, 3- to 3.5-μm 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 [1]. Cryogenic targets are used to maximize the fuel density in ICF implosions. These targets consist of ~900-μm-diam microcapsules that are permeation filled with over 1000 atm of D2 (deuterium–deuterium) or DT (deuterium–tritium) gas and then cooled to ~18.7 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 [2].

The layering process relies on the target being in an isothermal environment—the layering sphere that is uniformly illuminated by 3- to 3.5-μm, mid-IR light. The wavelength is tuned to
the absorption peak in the fuel material (3160 nm with 22-nm FWHM for 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. 1). 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 [3]. Until recently, this was the only choice to achieve the required power of >100 mW in this wavelength range. The development of a mid-IR, GaSb-based quantum well diode that produces >100 mW of output power at room temperature [4–6] 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.

2. 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-μm emitter is shown in Fig. 2. The cladding layers were 2.5-μm and 1.5-μm-wide Al$_{0.6}$Ga$_{0.4}$As$_{0.05}$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 Al$_{0.2}$In$_{0.8}$Ga$_{0.6}$As$_{0.02}$Sb$_{0.98}$ waveguide layer with a total thickness of about 800 nm contained two 12-nm wide In$_{0.54}$Ga$_{0.46}$As$_{0.23}$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-μm-wide, oxide-confined, gain-guided lasers. Two-mm-long neutral-reflection (NR ~30%) and high-reflection (HR ~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 [4]. Currently the diode lasers with output power >200 mW can be safely operated. Figure 3 shows output-power versus driver-current dependencies at various temperatures. The output power slightly decreases as the temperature increases, as expected.

3. 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. 4). 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. 5.
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 the current at constant TEC temperature [see Fig. 6(a)]. Once the current is set the spectral shape is stable. To provide the required spectral and output-power stability the diode laser’s output power should be set for maximum and then the laser should be temperature tuned to a D2-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. 6(b)]. The output divergence is typical for diode lasers and is ~65° along the fast axis and ~20° 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 7 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 nonoptimized 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 results with lasers that have smooth and compact spectra. This criterion can be met by the careful selection of diode lasers from different batches.

Fig. 6. The diode laser’s spectral shape and position change with (a) driver current as well as (b) beam profile. Data have been taken at 14°C.

Fig. 7. The diode laser’s spectral stability decreases with an increase of temperature.

4. Conclusion and future research

We have studied the spectral and output-power stability of a 3-µm-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**

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article. SUNY work was supported by US Air Force Office of Scientific Research under grant FA95500410372, and by US Army Research Office grant W911NF0610399.