Interferometric investigation of a diode laser source

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Diode lasers provide a coherent light source in the near IR. They have many desirable characteristics such as small size, high efficiency, a single-longitudinal mode output as large as 15 mW, and can be modulated at high pulse rates. An AlGaAs diode laser operating at 840 nm with an output of 6 mW was evaluated with a Smartt point diffraction interferometer. The wave front observed had astigmatism of ~2 λ present over the output beam divergence angle. In a modified Twyman-Green interferometer, the coherence length measured was >15 m with high visibility fringes. This source was found to be stable and highly linearly polarized. When used as an interferometric source, many possibilities for small scale interferometers and test equipment are now viable.

I. Introduction

Solid-state laser development has proceeded rapidly over the last several years. Diode lasers are one particular example. They are commercially available with cw powers of up to 50 mW for a single emitter with multilongitudinal modes and can have up to 100 mW for phased arrays of emitters. The highest powers recently reported are up to 2.6 W for a phased array. In a single-emitter single-longitudinal mode configuration, they can have a cw output of 15–20 mW.

There are many advantages of using a diode laser over a gas laser as an interferometric source. Diode lasers are attractive as coherent light sources because they are inexpensive, efficient, and compact sources, whereas gas lasers are inefficient and large. For a diode laser with 600 mW of electrical power in, 5 mW of optical power can be produced. This is much better than the typical gas laser which takes hundreds of watts of electrical power to produce a few milliwatts of optical power. Other advantages include: diode lasers have relatively long lifetimes of >10,000 h, can be operated at room temperature, the lasing wavelength can be varied by alloy composition, and the output of the diode can be monitored from the back side. Finally, diode lasers with a single-longitudinal mode have a very long coherence length.

The biggest disadvantage to this source is that it is not visible, which makes alignment difficult. Back reflections from the coupling optics can give rise to mode instabilities causing the output to hop between longitudinal modes. But, polarization components can be used to rotate the polarization of the return reflections orthogonal to the laser output. Finally, the laser output is sensitive to operating temperature. A substrate temperature change of 5°C will cause the lasing wavelength to change by 1 nm. Mounting the diode on a heat sink reduces this effect.

This paper reports the results of testing some properties of a diode laser. First, some background on diode lasers is given. Then the wave front quality of a Hitachi HLP-1400 laser diode is determined, and its coherence length is measured. Finally, possible applications of this source are given. Although this paper specifically refers to a Hitachi HLP-1400 diode laser, the properties presented here are common to single-mode diode lasers in general.

II. Background

AlGaAs diode lasers are composed of an alloy mixture of AlAs and GaAs. The relative amounts of these two crystals determine the lasing wavelength. With larger amounts of AlAs, the lasing wavelength will be shorter. Thus, it is possible to control the wavelength output of these sources to some extent when they are manufactured. Figure 1 shows a diode laser with a double heterojunction structure. The active layer consists of a 0.1-μm thick layer of AlxGa1-xAs. Typically, x is of the order of 0.05 to give an output wavelength of 830 nm. Most diode lasers are operable at room temperature. Mirrors of the resonant cavity are cleaved crystal faces. Thin-film coatings on the crystal facet determine the reflectance, which is usually ~30%. Most diodes are designed to let a large fraction of the power out one end,
Fig. 1. Double heterojunction structure for an HLP-1400 diode laser. The diode consists of layers of AlGaAs. Laser output is emitted through both ends.

Fig. 2. Far-field beam profile of an HLP-1400 diode laser. Note that the angular beam divergence is different for planes parallel and perpendicular to the junction plane. The far-field pattern is the Fourier transform of the beam at the crystal facet.

Fig. 3. Circuit for connecting the diode laser to the power supply to reduce the possibility of damage due to electrical transients. $R$ should have a value of 10–50 $\Omega$ and $C$ a value of 0.05 $\mu F$. $D$ is a high-speed silicon diode, and $DL$ is the diode laser.

III. Experiments

The HLP-1400 diode laser used in this investigation has a threshold current of 70 mA and room temperature output wavelength of 840 nm. Its output beam is horizontally polarized [direction parallel to the junction (Fig. 1)]. Stability of the output mode is assured as long as (i) the diode temperature is stabilized using a heat sink, (ii) the injected current is constant, and (iii) back reflections from the coupling optics which might interfere with the output are not present. For low output powers, small side modes exist along with the main laser line. These side modes decrease as the laser output increases beyond threshold. Maximum output power of this diode is 15 mW with its recommended operation at 2/3 of maximum. Experiments presented in this paper used 5 mW of diode output power.

There are precautions that must be taken when operating diode lasers. The biggest precaution is making sure electrical transients are avoided. Chances of destroying the diode this way can be reduced by connecting the diode to the power supply after the power is turned on with the voltage at its lowest setting. Once the diode has been connected, the power may be turned up slowly. Figure 3 shows a circuit which helps avoid transients. When operating, the diode should be thermally contacted to a heat sink and back reflections eliminated.

Wave front quality of this diode laser was ascertained using a Smartt point diffraction interferometer (PDI). Figure 4 shows a layout of this test. The Smartt PDI consists of a partially transmitting filter with a small centered pinhole (a few microns in size). To test a wave front, the beam is focused onto the filter. Part of the beam is diffracted by the pinhole creating a spherical reference wave, and the rest is attenuated as it passes through the filter. The aberrated test wave front interferes with the spherical wave to produce fringes viewable on a ground glass. To reduce aberrations caused by the imaging optics, the two lenses in Fig. 4 are positioned for minimum aberration using a He–Ne laser source. Residual aberration left after alignment is $\sim \lambda/10$. 

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Fig. 4. Schematic of wave front quality measurement setup. The diode laser output is focused onto a Smartt point diffraction interferometer (PDI), and the interference fringes are viewed on a ground glass.

Figure 5 shows interference fringes photographed through an IR viewer with the diode laser source. From digitizing these fringes, the diode laser has approximately one-half wave of astigmatism over the imaging lenses $f/11$ collecting cone. Wave front quality over the diode $f/2.5$ divergence cone is then 2 waves of astigmatism. This wave front can be improved using collimating optics with anamorphic correction; but, for many applications, this wave front is acceptable. Better coupling efficiency can be achieved with small $f$/Nos.; however, the wave front quality is better for large $f$/Nos.

The coherence length of the diode laser was measured using a modified Twyman-Green interferometer. With the diode laser as the source, the path length between the two beams of the interferometer was varied. The fringe visibility was very good for path length differences up to 15 m, corresponding to a single-mode line-width of $<20$ MHz. A typical He–Ne laser (not single mode) has a coherence length of 20 cm with a linewidth of $\sim 1.5$ GHz. With such large values for the laser coherence length, the path lengths do not have to be as closely matched as they would for a He–Ne laser.

IV. Applications

There are a number of applications for diode laser sources in optical testing and interferometry. One such application is phase shifting or heterodyne interferometry. In phase-shifting interferometry the phase of one beam of the interferometer is changed to produce a relative phase difference between the two beams. Data are taken with different relative phase differences and processed to obtain the test object’s phase profile. Frequency modulation of the diode laser output is one means of changing the relative phase difference between the two beams of the interferometer. Since 840 nm is near the peak of silicon response, the fringes obtained can be imaged onto a silicon CCD or diode array. A diode laser could be used to make a compact LUPI (laser unequal path interferometer or Twyman-Green) which may easily be moved to test a mirror in situ. Another application is in two-wavelength holography. The diode laser could be used either as one source or as both by changing the laser wavelength using the heat sink temperature. A final application would be for electronic speckle pattern interferometry (ESPI). ESPI systems usually include a silicon solid-state array for imaging the speckle patterns, which is compatible with a near-IR source. With a fiber creating the reference beam, a perfect spherical wave can be obtained even with an astigmatic wave front. Since the object beam is a speckle pattern, its wave front quality is not important.

These are not all the applications which can be envisioned. They are just a sampling of the possibilities to show the flexibility of using a laser diode.

V. Conclusion

Diode lasers provide a single-mode interferometric source which is compact and highly efficient. Because they output a single mode, they have a long coherence length to enable uneven path lengths. Acceptable wavelength quality is available without correcting optics for applications using a large $f$/No. or those where source aberrations do not matter.

References