Thermal profile of high power laser diode arrays and implications in line-narrowing using external cavities

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Abstract: We present measurements and analysis of thermal profiles of high power laser diode arrays. We determine the limitations the profile imposes on the linewidth of the diode array in an external cavity configuration and discuss applications in optical pumping for hyperpolarized MRI.

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Hyperpolarized noble gases are used in novel magnetic resonance imaging (MRI) systems to allow low magnetic field imaging and high resolution of gas spaces (e.g. lungs). The hyperpolarized gases are composed of long-lived meta-stable states of spin ½ noble gas nuclei and are generated via a hyperfine interaction with the polarized valence electrons of optically pumped alkali metal vapors in a gas mixture[1]. For large volume generation, the rate of photon absorption by the alkali metals must be much greater than all decay processes, requiring more than 10 W of power absorbed per liter. The absorption is proportional to the overlap of the laser spectra with the pressure-broadened linewidth, which is 0.2nm/atm for Rubidium, the most commonly used alkali metal. Laser diode arrays are best suited for this application due to their size, cost, wall-plug efficiency and high available power. However, they are not optically efficient due to their large inherent linewidth, approximately 2nm for current commercially available laser diode arrays.

The linewidth can be narrowed using an external cavity, which increases the pumping efficiency due to a larger overlap with the absorption despite reduced total power output. In our experimental setup (shown schematically in Fig.1), we use a cylindrical microlens to collimate the fast axis of the diode array and an imaging system to image the slow axis onto a grating, similar to systems previously demonstrated,[2] generating an individual cavity for each of the diodes The combination of the grating with the output facet results in a wavelength selective effective reflectivity[3] providing a gain margin for the modes under feedback, causing them to be accentuated while diminishing the other modes.

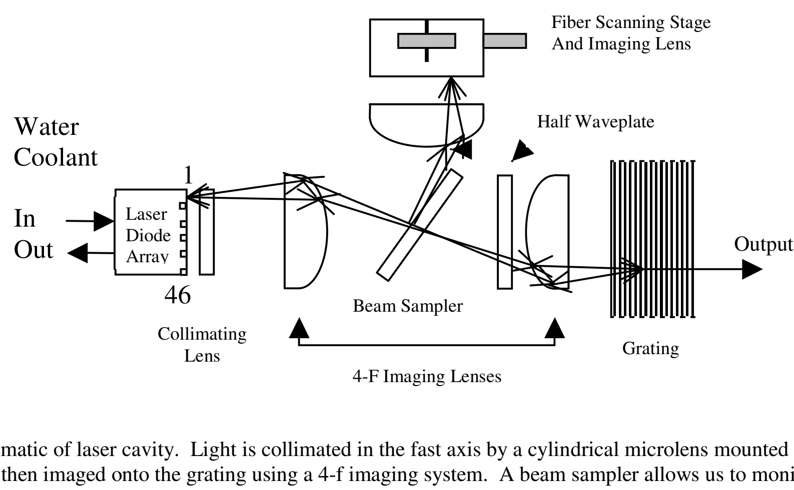

Fig. 1. Schematic of laser cavity. Light is collimated in the fast axis by a cylindrical microlens mounted on the diode array. The light is then imaged onto the grating using a 4-f imaging system. A beam sampler allows us to monitor the emission characteristics intra-cavity, with or without the feedback. We use a fiber to collect the light allowing us to measure each diode separately. The beam path is shown for the top diode.

External cavity line narrowing is successfully used for single element laser diodes. However, current high power water-cooled laser diode arrays have thermal profiles due to non-uniform heating and cooling effects. This causes a shift of 0.25nm/ºC [4] in the peak wavelength of the gain profile for each diode and increases the overall linewidth of the array. Resulting linewidth is approximately twice of the single diode linewidth of 1.2nm. In Fig. 2a we show the spectra of five diodes on a 46-emitter 10W laser diode array equally spaced on the bar. By fitting the emission peak we can determine the temperature shift of the diode and thus determine the thermal profile of the bar, the result of which is shown in figure 2b. The non-uniform thermal profile also causes an effective detuning of the feedback, reducing the available gain.

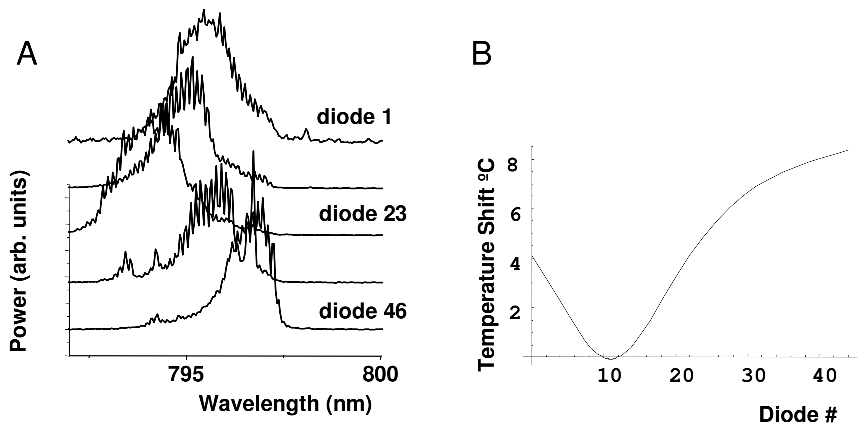

Fig. 2. a) Spectra at five points equally spaced along the bar. The diode numbers are in reference to fig. 1. b) Thermal profile of the array fitted from the spectra. The temperature shift is given relative to the coldest diode. The profile is asymmetric due to the heating of the coolant as is flows across the array.

We will present experimental results on limitations of line narrowing due to detuning of the gain spectrum on commercially available laser diode arrays. In our studies, we monitor the spectra of individual elements under varying feedback conditions and temperature profiles, directly linking the line narrowing limitations to thermal effects. Our results will identify the minimum linewidth as well as maximum power output obtainable with ideal cooling for high power laser diode arrays that will allow optimization of optical pumping systems for generating hyperpolarized noble gases for magnetic resonance imaging.

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