Spectrally narrowed 1.5 kW optical pumping laser for large-scale SEOP production of hyperpolarized gases

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INTRODUCTION

In earlier work we reported that efficient and scalable production of hyperpolarized xenon could be accomplished by saturating the flowing xenon and buffer gases with rubidium in an unilluminated section of the polarizer, then directing the saturated mixed gases through a long polarizing cell against the direction of propagation of the laser beam, and subsequently continuing that flow in the same direction in a cold section of the polarizing cell, in the presence of the laser beam to condense the rubidium [1]. We later reported that this process could be scaled up by increasing the laser power, however only if we simultaneously improve the removal of the heat from the flowing gases [2]. This was accomplished by assembling the polarizing cell from copper plates arranged to confine the gas flow along narrow copper channels [3]. This geometrical arrangement of a long narrow polarizing cell adds the requirement of low angular divergence of the laser beam to the other design challenges of high power and narrow spectral width.

METHODS

Two commercial stacks each consisting of twelve fast-axis-lensed diode bars drive the laser system. Output light from each stack enters a magnification M=3 afocal telescope and is subsequently directed through a segmented turning mirror and imaged on a grating inclined at the Littrow angle. The segments in the turning mirror, one for each bar of the grating, are positioned along a stepped geometry to alter the optical path lengths of off-axis bars, such that the distance between the light source and image on the grating is equal for all bars, allowing for a perfect focus [4]. With this configuration, the wavelength selected for each emitter by feedback in the external cavity depends directly on the angle between the direction of the incident beam from that individual emitter and the plane of the grating. Manufacturing imperfections in the flatness of the diode bars, so called "smile", is transformed into angle variations after the fast-axis microlens, and dominate the overall linewidth of the wavelength-locked laser output. For our grating and angle, the change corresponds to 1.3 milliradian/nanometer (mr/nm). In order to remove this remaining variation, we characterized residual imperfections in the output of each laser bar stack emitter-by-emitter. Two parameters were measured: angular deflections caused by laser bar "smile" and greater-than-optimal divergence due to microlens distance variations. A correction plate with a corresponding array of curved prisms was fabricated consisting of unique correction elements for each emitter [5]. This correction plate was permanently attached 2mm in front of the laser stack.

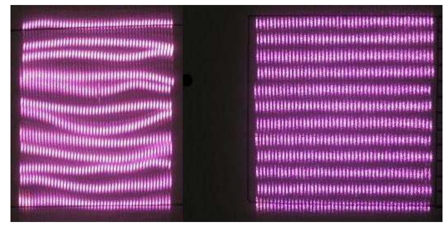

Fig.1. Reduction of "smile" for one 12-bar stack, shown before and after implementing a correction plate in front of the microlenses (for angle reference bars are offset by 2mr).

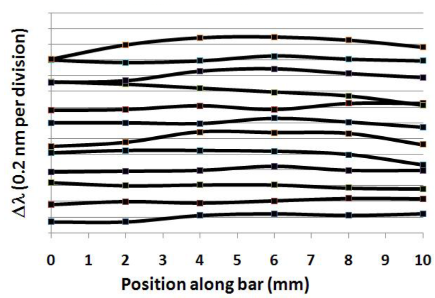

Fig.2 Wavelength spread after plate correction shows large improvement as measured at several points within each of the twelve bars (0.2nm offset between bars is artificial for better visualization).

RESULTS

The correction plates, custom designed and fabricated for each of the laser stacks, were able to significantly improve the uniformity of the optical axis directions and reduce the divergences of the individual emitters' beams. We present a comparison of the stack output before and after attachment of the correction plate (Fig.1) using an optical setup that images position in the horizontal direction and disperses angles in the vertical direction such that the average smile approximately equals the offset between bars (2mr). The uniformity of the corrected emitter angles, better than 1mr (0.3mr at the grating), is at least a factor of five better than before. The wavelength-locked spectrally-narrowed outputs of emitters from corrected laser stacks installed into our external cavity were compared to the outputs with uncorrected stacks. Spectra were acquired for emitters at six positions along each individual bar. Locked outputs of uncorrected stacks varied by almost 1.0 nm corresponding to 1.3mr variations (4mr at the laser output), with most emitters lying within 0.5nm. Locked outputs of corrected stacks had variations reduced below 0.2nm (Fig.2), with most emitters locked to wavelengths within 0.1nm of one another. The overall fast-axis divergence of the output laser beam is also reduced to below 0.1mr by this improvement. The optics magnifies the beam along the slow axis by a factor of 14, reducing its divergence from 3 degrees to 4mr. Measured power output from two stacks at 80A current (70% of the 110A design maximum for these stacks) was 1.5 kW with overall spectral line width below 0.2 nm.

DISCUSSION

Refinements to the laser optics described above are particularly well suited to polarization of hyperpolarized gases using SEOP. A xenon polarizer is being commissioned incorporating the two stack 1.5kW laser whose measurements are reported here (Fig.3.) A helium polarizer with two such lasers is also under development.

Fig.3 High production xenon polarizer incorporating this high-brightness spectrally-narrowed laser.

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REFERENCES:

[1] I.C. Ruset, et al. *Phys.Rev.Lett.* **96**: 053002 (2006);
[2] F.W.Hersman, et al. *Acad.Radiol.***15**: 683 (2008).;
[3] J.H.Distelbrink, et al. *Proc ISMRM* #1776 (2008);
[4] F.W. Hersman,et al. US Patent #7769068, pending in Europe;
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