Improving optical pumping efficiency in the production of hyperpolarized noble gases for MRI applications

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Interest in the use of hyperpolarized (HP) noble gases ^{3}He and ^{129}Xe in magnetic resonance imaging (MRI) and spectroscopy (MRS) has significantly increased in recent years[1]. The nuclear spin polarization of isotopes ^{3}He and ^{129}Xe can be increased by four to five orders of magnitude through optical pumping. This extraordinary gain in spin polarization directly translates to a signal gain in MRI and MRS. For example, HP ^{3}He has been used for imaging of lungs particularly the air spaces of the lung which has typically resisted conventional MRI techniques in the past. Early results on animals as well as on humans have indicated that hyperpolarized noble gas MRI can have profound diagnostic and therapeutic implications for diseases of the lung. The high Xe solubility in the blood and tissues may also open possibilities of imaging other organs such as the brain, kidney and heart using hyperpolarized ^{129}Xe.

The production of HP noble gases ^{3}He and ^{129}Xe is a key requirement for hyperpolarized noble gas MRI and MRS. HP ^{3}He and ^{129}Xe can be produced using the spin-exchange optical pumping (SEOP) method. Economically, the HP gases need to be prepared on site. As a laser source for SEOP, diode lasers are the most popular choice because of the low cost and small footprint. The use of diode lasers, however, does bring a disadvantage. The spectral output of diode lasers is typically a couple of nm wide and this makes the optical pumping less efficient. In this paper we describe our research directed toward efficient, cheap production of both HP ^{3}He and ^{129}Xe by optically optimizing the pumping process. We present our results on frequency narrowing of a 40W LDA.

In the SEOP process, angular momentum is transferred from circularly polarized light to the electrons of alkali metal atoms through optical pumping, then to the nuclei of noble gas atoms through spin-exchange collisions, creating a large non-equilibrium nuclear polarization. Rubidium is often the alkali metal of choice for SEOP, due to the availability of high power laser sources for optical pumping at the 794.7nm D1 resonance. The efficiency of the process depends on many factors including the available laser power at the Rb absorption line, the linewidth of the resonance, the gas mixture, the partial pressures of the gases in the mixture, and the density of Rb atoms in the spin exchange vessel. As the major limiting factor is the available laser power, we have concentrated our efforts on improving the spectral power density of high power laser diode arrays using optical feedback from a grating, and matching the linewidth of our laser source to the linewidth of the resonance. Similar methods have previously been used to narrow the spectral output of a single 4W laser diode[2] and a 20W LDA[3]. We narrow a 40W LDA to achieve a seven-fold increase in spectral power density. Despite 25% losses due to the narrowing optics, a five-fold increase in number of useful photons is still achieved. Depending on the pressure broadening in the SE vessel, this can make our narrowed laser as effective as a 200W free-running laser. Figure 1 shows our laser spectrum before (red line) and after (blue) frequency narrowing.

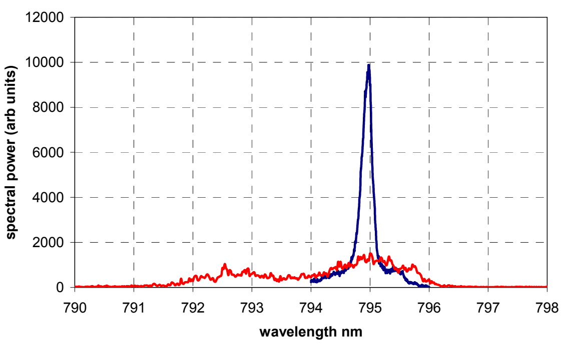

Figure 1 *Laser frequency spectrum before (red) and after (blue) spectral narrowing. At the wavelength of interest (795nm) we have a sevenfold increase in spectral density.*

Pressure broadening is the main broadening effect of the Rb D1 line in a spin exchange vessel. 3He, 4He, and N_2 can all be used to pressure broaden the Rb D1 line. We performed SEOP of ^{3}He at 5 amg, at 368±5 K. We recorded laser absorption at the Rb D1 resonance with both free-running and frequency narrowed laser light, as shown in figure 2. We estimate that less than 10% of the laser light is absorbed in the free-running case, whereas more than 70% of available light is absorbed in the frequency-narrowed case. We have completed the construction of the setup for production of HP ^{3}He, and are currently (Nov. 2003) constructing a flow system for HP ^{129}Xe production. HP ^{129}Xe has been previously produced using a 140W LDA[4] and also a 210W diode array system[5]. We expect our frequency narrowed 40W laser to be approximately as effective but less costly than these systems for HP ^{129}Xe production. The performance of the frequency narrowed laser in the production of HP 3He and 129 X will be discussed in our presentation.

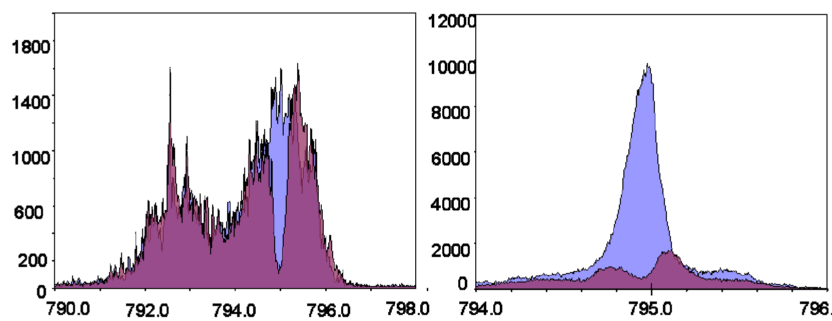

Figure 2 *Rb absorption spectrum before (left) and after (right) spectral narrowing. Without narrowing we see less than 10% of photons are absorbed, and after narrowing more than 70% are absorbed.*

We are grateful to Brian Saam for guidance during the construction of our ^{3}He apparatus, and for providing us with high quality spin exchange cells.

1. Moller HE, Chen XJ, Saam B, et al. (2002). *Magnetic Resonance in Medicine* **47**(6): 1029-1051
2. Nelson, I. A., B. Chann, et al. (2000). *Applied Physics Letters* **76**(11): 1356-8.
3. Chann, B., I. Nelson, et al. (2000). *Optics Letters* **25**(18): 1352-4.
4. Driehuys, B., G. D. Cates, et al. (1996). *Applied Physics Letters* **69**(12): 1668-70.
5. Zook, A. L., B. B. Adhyaru, et al. (2002). *Journal of Magnetic Resonance* **159**(2): 175-182.