High Production of Hyperpolarized Helium-3: Commercial Prototype

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Introduction

Although hyperpolarized gas MRI has been demonstrated for over a decade [1], progress and clinical applications are still limited by the availability hyperpolarized gas. Hyperpolarized ^{3}He is produced through spin-exchange optical pumping (SEOP) and metastability-exchange optical pumping (MEOP). Even though a few large production facilities based on the MEOP exist (e.g. at Mainz, Germany [2]), the system cost and the large space requirements exemplify the gas production difficulties that have discouraged its wider use by the research community.

To meet the potential demands of the hyperpolarized gas community Xemed LLC (Durham, NH) is developing a high-volume production hyperpolarized ^{3}He hybrid SEOP system which can easily fit in a research or clinical environment. The basic design, numerical modeling, and our first experimental results are presented. While the polarizer is a scale-up of a typical SEOP system, many novel ideas were implemented including the hybrid Rb-K optical pumping [3]. The system is designed to produce 100 liters of hyperpolarized ^{3}He a day with polarization of ~70% limited only by the X-factor [4] of the cell.

Methods

The main polarizing cell is a large glass cylinder of 9.4 cm ID and 120 cm long (~8.3 liter internal volume). The cell is placed inside a pressurized vessel made from an aluminum cylinder with hermetically sealed top and bottom flanges. Both flanges have optical windows for laser entrance and exit. By balancing the pressure in the containment vessel with that inside the cell, we can safely operate the polarizer at high pressure (~6-10 atm), which significantly increases its capacity. The balanced pressure minimizes the required wall thickness of the cell. In our initial testing, the cell is continuously pressurized to 1 atm. The temperature of the cell is controlled using a copper jacket surrounding the glass cell. Copper tubes brazed to the main copper jacket carry flowing silicone oil, whose temperature is externally controlled using pipe heaters and radiators. The glass cell, heater, and instrumentation are incorporated into a modular cartridge design that allows all the feedthrough connections to be made prior to the final insertion into the aluminum pressure vessel. Once assembled the pressure vessel is lowered into the structural tower containing the solenoid and the coils.

The optical pumping laser power is provided by two 12 diode-bars each CW high power diodes (2.2 kW nominal power and 2.5 nm FWHM). Because of the high pressure of the cell, no spectral narrowing is needed. The optical setup consists from a shifting Rhombic prism and a telescope with a magnification of five. A custom water-cooled aluminum block cuts the beam into a circular shape from its original square form. The system is designed to provide more than 1.5 kW for optical pumping of Rb.

The magnetic field is generated by a solenoid (39 cm dia., 135 cm long) and four coils for improving field uniformity on the top and bottom of the solenoid. The polarization is measured using a spiral-shaped surface coil built in between two layers of peek film. Proton signal is easily observed at 93 kHz resonant frequency with solenoid field uniformity of ~100 ppm. Helium polarization is measured relative to that of protons (thermal).

Results

We are currently in the midst of an experimental program to estimate optimum conditions for polarizer operation, optimum K-Rb mix ratio, and the laser power. Our modeling shows that an alkali ratio of 10:1 K-Rb (by mass) and operating temperatures of 220-250^{o}C will best match our available laser power and cell size. Fig.1 shows estimates of polarization as a function of laser power and for different pressures inside the glass cell.

Our first test used a Pyrex cell and electrical heating system. The cell was filled with 890 torr of He-3 and 150 torr of N2. The cell was charged with Rb rather than a K-RB mixture because of the lower temperature requirements due to the Pyrex material. The system was heated to 160-180^{o}C. The laser power was restricted to 400-500 W due to the fact that the uncooled walls allowed thermal stratification to occur within the cell, causing high Rb concentration and excessively high temperature near the top. Nevertheless, we measured polarization levels of ~6% for T1 relaxation times of the cell of 50 minutes which was in good agreement with our modeling.

Future experiments will incorporate wall temperature control which will allow for higher laser power and should produce higher polarization. Other planned developments include a novel laser which will provide more the 2.5kW and a divergence of less than 2mrad and the use of other cells with different wall treatments and made from different materials. Alkali coating of the walls will significantly reduce the wall relaxation, greatly increasing T1. We are looking in replacing Pyrex with aluminosilicate glass, well known for its low helium permeability, high relaxation time, and good resistance to alkali attack. Numerical calculations predict that the system could produce two batches of 50 bar-liters (cell at 6 atm) of polarized ^{3}He daily with polarization of ~70% for cells with T1 in excess of 20h and X-factor less than 0.2.

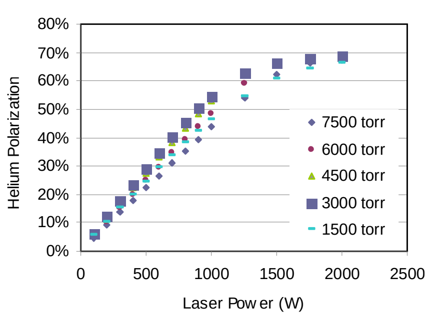

Fig.1: Estimates of the helium polarization as a function of the laser power at 250^{o}C temperature and for an alkali mix ratio of 10 (K/Rb). The X-factor was considered 0.2, laser spectral width of 2 nm, and T1 of 20h.

Fig.2 Top flange contains the required feedthroughs, including the polarizing cell gas line for adding and removing hyperpolarized helium.

Fig.3 First assembled system shows the high power laser temporarily mounted on top of the vertical metal box containing the polarizer.

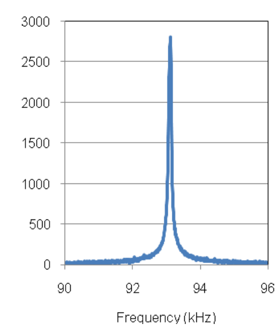

Fig.4 Helium signal observed in a single shot during polarization build-up. The signal shown corresponds to ~2% polarization.

References:

[1] M.S.Albert et al. *Nature (London)* **370**: 199 (1994).

[2] J.Becker, J.Bermuth, M.Ebert *et al Nucl. Instr. Meth.* **402**: 327 (1998)

[3] E. Babcock, I. Nelson, S. Kadlecek et al. *PRL* **91**: 123003 (2003)

[4] E. Babcock, B. Chann, T.G. Walker et al. *PRL* **96**: 083003 (2006)