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SPECTRAL LINE AMPLITUDES OF THERMALLY POLARIZED ^{129}XE IN COMPARISON WITH HYPERPOLARIZED ^{129}XE

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Abstract: *We present the experimental results of hyperpolarized ^{129}Xe spectral line amplitude obtained by 4.7 T NMR system and high power semiconductor laser with reduced emission linewidth. The hyperpolarization process was based on the spin exchange collision technique between ^{129}Xe atoms and optically pumped Rb atoms. The amplification of the ^{129}Xe spectral line amplitude about 400 times was achieved. Furthermore, the influence of the optical pumping duration to the ^{129}Xe spectral line amplitude was surveyed.*

Key words: *hyperpolarized, xenon, ECL laser, spectral line amplitude enhancement*

INTRODUCTION

The hyperpolarized noble gases (^{129}Xe, ^{3}He) play major role in the biomedicine and in the inanimate nature applications too.

We are concerned with the hyperpolarized xenon-129 (^{129}Xe), which has become attractive as a contrast medium in magnetic resonance imaging (MRI).

The powerful technique of MRI of human body has a limited ability to examine organs with low water content and/or with air spaces, such as colon or lungs. An introduction of a highly contrasting ingredient would significantly extend its potential. Gaseous ^{129}Xe is normally not present in a human body, so the experiments do not suffer from unwanted background signals. Moreover, the hyperpolarized ^{129}Xe acts as a non-radioactive source of a very strong NMR signal, which can even lead to introduction of specialized simple MRI apparatuses with significantly less powerful magnets. These applications show that hyperpolarized gases may become a useful tool for a non-invasive investigation of human lung ventilation, giving an access to static imaging during breath hold, dynamics of inhalation or exhalation and functional imaging, e.g. [1].

Besides the biomedical applications, hyperpolarized xenon (HpXe) can be used with an advantage to improve studies of the molecular structure and dynamics in such systems as zeolites, catalysts, semiconductors, nanocrystals, liquid crystals, polymers or proteins [2, 3].

The study and application is based on the chemical shift in ^{129}Xe gas. At very low hyperpolarized xenon pressures and at room temperature, the chemical shift is sensitive to the interaction of xenon atoms with the material walls. It leads to the further mentioned study of microporous materials [4].

1 EXPERIMENTAL ARRANGEMENT

Basic experimental arrangement, which we had assembled in order to be able to perform the experiments with HpXe, consisted of two crucial parts, as shown in Figure 1.

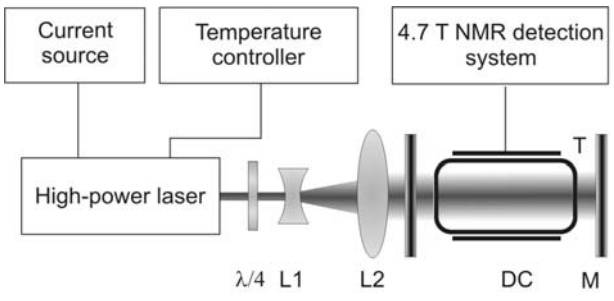

Figure 1: Experimental arrangement. λ/4 is a retardation quarter-wave plate, L1 and L2 is an optical telescope, DC is detection coil, T is a target cell and M is 4.7 T magnet.

The first part is a commercially available 4.7 T NMR system with MR Solutions Ltd. controlling electronics. It is used together with home-made saddle coil for ^{129}Xe spectral line detection. Dispersal magnetic field of 4.7 T NMR system was used as a source of magnetic field of magnitude 16 mT. The homogeneous magnetic field splits the Rb energy levels to two sublevels. For optical pumping was used the circularly polarized laser radiation, which excites Rb atoms with defined magnetic spin.

The source of the laser radiation is the second one of the two mentioned crucial parts of the presented arrangement. The main component of the laser system is a high-power laser diode S-λ-3000C-200-H (Coherent). The maximum output CW power is approximately 3 W and the central wavelength is about 797 nm at the temperature of 25°C. Due to the efficiency of the Rb atoms optical pumping process, the laser diode emission linewidth had to be reduced. To achieve the laser diode emission linewidth reduction, a diffraction grating was used [4]. It was applied in Littrow configuration as a wavelength selective feedback.

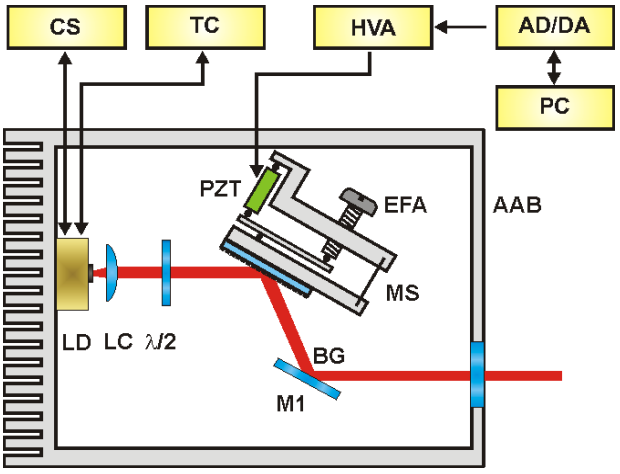

Figure 2: Block diagram of the designed laser system. CS is current source, TC is temperature controller, HVA is high voltage amplifier, AD/DA is AD-DA converter and PC is personal computer, LC is aspheric collimating lens, λ/2 is retardation half-wave plate, BG is diffraction grating in Littrow configuration. PZT is piezoelectric transducer, EFA is extremely fine adjustment screw, MS is flexible plate. M1 is mirror and AAB is aluminum alloy box.

With experimental setup, shown in Figure 2, we were able to reduce the laser diode emission linewidth more then 10 times, from 1000 GHz to 69 GHz full width at half maximum, shown in Figure 3. The power loss was 49%, from 3.14 W to 1.60 W.

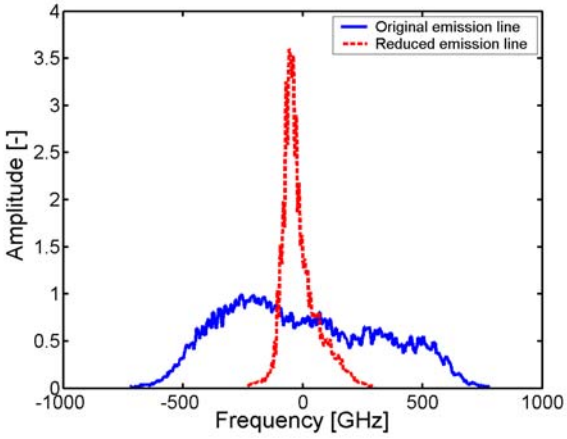

Figure 3: The laser diode emission lines. The solid curve is the LD original emission line and the dashed curve is the reduced emission line.

2 EXPERIMENTAL DEVICE

The target cell used for measurement was a simple 9.2 cm long cylinder with an inner diameter of 3.5 cm. The cell was made from borosilicate glass with flat windows. It was enclosed in a Teflon box to allow thermostatization by a hot-air flow. The box with target cell was placed in front of the 4.7 T NMR system in homogenous 16 mT magnetic field.

A small amount of Rb was moved into the cell under vacuum conditions. Before the cell sealing, it was filled with a mixture of xenon ^{129}Xe (100 kPa) and nitrogen N2 (200 kPa). The target cell was then heated to 100°C and the Rb vapour was optically pumped for 30 minutes. Afterwards, the target cell was placed into the 4.7 T NMR system to obtain ^{129}Xe spectral line.

3 EXPERIMENTAL RESULTS

The spectral lines of thermally polarized and hyperpolarized ^{129}Xe were measured. The xenon gas includes natural abundance of isotope ^{129}Xe. The spectral line of thermally polarized ^{129}Xe was measured after 3 hours in 4.7 T NMR system, the spectral line of the hyperpolarized 129Xe was measured after 30 minutes of optical pumping. Both spectral lines are shown in Figure 4. The amplification of the spectral line amplitude is about 400 times.

The influence of the optical pumping duration to the ^{129}Xe spectral line amplitude is shown in Figure 5. The optimal optical pumping time to achieve sufficient hyperpolarization starts at 10 minutes. Relaxation time T_1 is 26.9 minutes for natural state and 27.6 minutes for hyperpolarized state under given conditions.

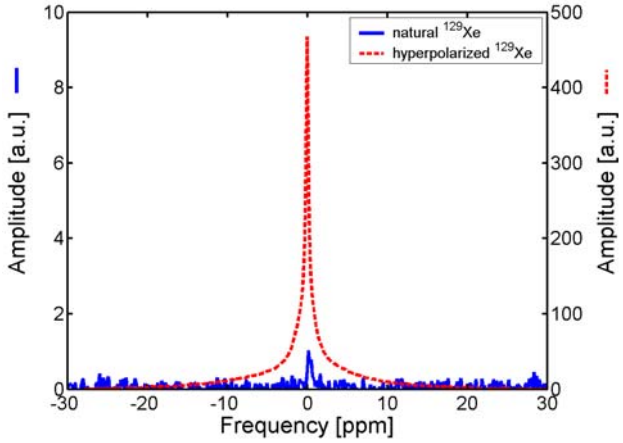

Figure 4: Spectral line of thermally polarized ^{129}Xe (blue) and hyperpolarized ^{129}Xe (red)

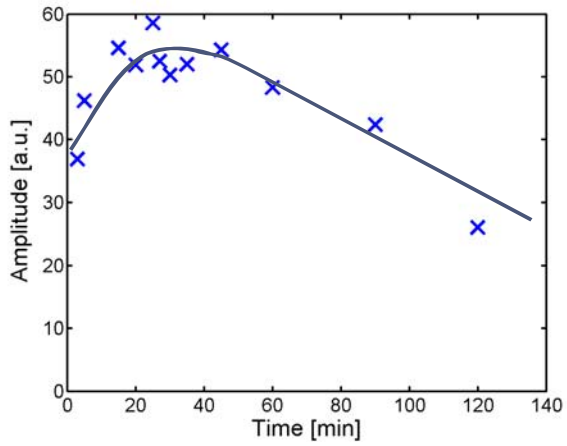

Figure 5: Dependence of amplitude of hyperpolarized xenon spectral line on duration of laser optical pumping

4 CONCLUSION

We assembled an experimental arrangement for ^{129}Xe hyperpolarization that consists of 4.7 NRM system and high-power laser diode.

We obtained the ^{129}Xe spectral line for natural and hyperpolarized state. The amplification of the spectral line amplitude is about 400 times. The influence of the optical pumping duration to the ^{129}Xe spectral line amplitude was surveyed.

We constructed a special laser system for Rb optical pumping [5]. The emission linewidth was reduced from 1 THz to 69 GHz with a half of the total optical power loss.

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