ARRANGEMENT FOR PRODUCTION OF HYPERPOLARIZED XENON

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ABSTRACT

The rapidly growing interest in production of hyperpolarized noble gasses (HpG), predominantly ^{3}He and ^{129}Xe for Nuclear Magnetic Resonance (NMR) experiments is driven by potentially attractive medical applications. Neither helium nor xenon is normally present in the body, so the experiments do not suffer from unwanted background signals. Among the potential medicine applications, the opportunity to image organs with low water content and/or with air spaces, such as colon or lungs, has raised a considerable interest. Current conventional imaging techniques cannot provide good images of these hollow spaces, and not even of the surrounding tissues. These applications show that HpG may become a useful tool for non-invasive investigation of human lung ventilation, giving access to static imaging during breathhold, dynamics of inspiration/expiration, and functional imaging.

One of the two techniques and the more promissing one of achieving the hyperpolarized state of noble gasses is based on the spin-exchange collision between atoms of Rb and ^{129}Xe. This paper describe the way of optical pumping of Rb vapour by Ti:Sa laser which is necessary for attainment hyperpolarized state of ^{129}Xe.

1 INTRODUCTION

The phenomenon of angular momentum transfer by the exchange of spin between optically pumped Rb atoms and nuclear spins of ^{3}He was first reported by prof. Bouchiat and theoretically described in [1]. With the higher efficiency of the polarization process that the spin-exchange technique namely of ^{129}Xe can offer, this technique became the mainstream in HpG production and experiments. The first experiments with optical pumping of Rb vapour employed a Rb lamp or dye lasers. When the first commercially available titanium-sapphire (Ti:Sa) lasers appeared, they proved to be a useful replacement for dye lasers in many spectroscopic applications. We employed a commercial Ti:Sa laser for our experiments for its easy wavelength tuning and narrow linewidth.

The Ti:Sa laser output radiation is lineary polarized and this is absorbed by both magnetic substates m=±1/2 of the Rb 5s $^2S_{1/2}$ ground state. Unlike for the production of hyperpolarized noble gasses (namely ^{129}Xe) the light absorption by the one magnetic substate is necessary. This is ensured by the circularly polarized light which can be generated by introduction of a quarter-wave plate. For example, right circularly polarized light selectively excites population from the m=-1/2 ground state to the m=1/2 excited state. Relaxation of the exited state brings population down to both ground states, m=1/2 and m=-1/2. Under continuous radiation, the m=-1/2 ground state will be depleted and population will subsequently accumulate in the m=1/2 ground state, leaving the Rb electrons spin-polarized. The Rb polarization is subsequently transferred to ^{129}Xe nuclear spins through spin-exchange collisions. For Zeeman splitting of ground state to substates m=±1/2 is necessary to apply a homogenous magnetic field, which is generated by a set of Helmholz coils.

2 ARRANGEMENT FOR OPTICAL PUMPING OF RUBIDIUM

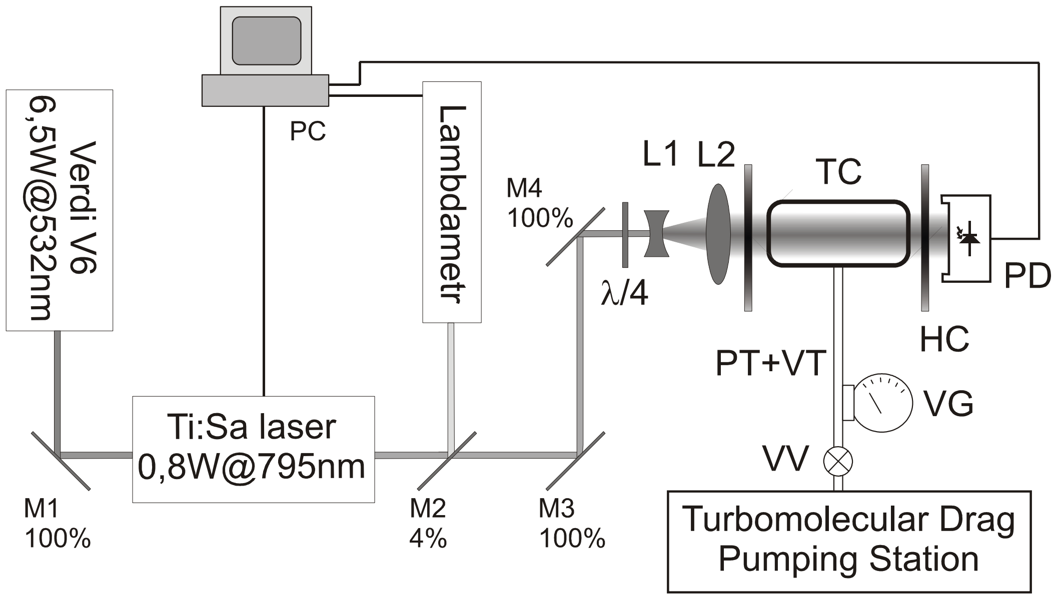

Fig. 1: *Experimental set-up for optical pumping of rubidium. M1, M2, M3, M4 - mirrors, l/4 - quarter-wave retardation plate, L1 - diverging lens, L2 - converging lens, TC - target cell, HC - Helmholz coils, PD - photodetector, PT - plastic tube, VT - vacuum hose and VV - vacuum valve*

2.1 OPTICAL SETUP

The whole arrangement consists of a CV COHERENT Ti:Sa laser pumped by a 6.5 W Nd:YAG VERDI laser, beam forming optics, and the target cell. The laser beam is lifted by a periscope to fit in the cell placed in the center of Helmholz coils. Diameter of the beam is expanded by a telescope and a circular polarization of the light is generated by a retardation quarter-wave plate. The telescope is used to expand the beam width. The output laser beam width of approx. 0.3 mm (FWHM) was expanded to the width like matching the diameter of the absorption cell (35 mm) by Galileo telescope consisting of diverging and an converging lenses.

2.2 TI:SA LASER

We used a commericial Coherent Ti:Sa laser, model 899-01. It is a flexible, convertible ring laser that can operate as a conventional dye ring laser, or a solid state ring laser using titanium:sapphire as the gain medium. Pumping is done by solid-state diode-pumped, frequency-doubled Nd:Vanadate (Nd:YVO_4) Coherent Verdi V-6 laser that provides single-frequency green (532 nm) output at power levels greater than 6 Watts. Parameters of the laser are in tab. 1.

Parameter	Specification
Output Power	<1W (6.5 W pumping power)
Wavelength	680 nm - 1025 nm
Polarization	vertical
Linewidth	>20 GHz
Linewidth with ethalons	<10 MHz

Tab. 1: *Important parameters of Ti:Sa laser model 899-01*

Wavelength of the Ti:Sa laser is tunable in a wide range (680 nm - 1025 nm) by birefringent filter. The birefringent filter is controlled manually by micrometer adjusting system. To keep the continuous pumping proces running for a longer time electronic control of the lasing wavelength was necessary. We extended the tuning screw by piezoelectric element. This allowed us to tune the laser electronically over 0.25 nm which exceeds by far thermal wavelength drifts. A great sensitivity of the laser to dust particles led us to place it to a separate clean box slightly over-pressurized by nitrogen generated by evaporation from a liquid state.

2.2.1 SOFTWARE FOR TUNING AND WAVELENGTH CONTROL OF TI:SA LASER

In our laboratory arrangement, we designed the tuning and wavelength control of the Ti:Sa laser by of a PC (personal computer), an AD/DA converter card, and high voltage amplifier driving piezo transducer. Control of the system is performed by software written in LabVIEW environment. The communication between a personal computer and AD/DA converter card is ensured by CAN bus. The program works in two different modes. The first allows manual search of the desired absorption line of rubidium by coarse screw tuning. Than the triangular-signal generator is used for matching of the line into the center of tuning range and the stabilization loop is activated. The second one mode allows automatic detection of the absorption line. In the second regime after a manual coarse tuning the program monitors variations in detected signal and if the absorption line is found out, the stabilization loop is activated automatically. In both of this cases the Ti:Sa laser wavelength is stabilized on the center of the absorption line of rubidium at the wavelength 794.76 nm to achieve the maximum efficiency of the optical pumping process. All of the parameters and constants can be set and modified during running of the program. Important values of measurement are recorded to a text file.

2.3 TARGET CELL

The cell used for measurement was a simple cylinder 9.2 cm long. The cell is made of 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 Helmholtz coils system. designed to generate a homogenous 10 mT magnetic field with a precision $2.18*10^{-4}$.

The cell is attached to a vacuum manifold by non-magnetic vacuum components. A small amount of Rb was moved into the cell under vacuum conditions and a mixture of gasses could be fed into the cell through separate valves. The main part of the evacuation system was Turbomolecular Drag Pumping Station TSH 071 E by Pfeiffer Vacuum GmbH. The whole evacuation system allowed evacuation down to a pressure of $8*10^{-5}$ Pa.

3 EXPERIMENTAL RESULTS

During the optical pumping and spin-exchange process, the optical frequency of the pumping laser beam should be tuned close the center of the Rb transition. At the same time the linewidth of the pumping beam should be fitted approximately to the linewidth of the selected Rb transition. If both conditions are fulfilled then a maximum efficiency of the energy transfer is possible. The tuning of the Ti:Sa laser is possible by tilting of a birefringent filter and its linewidth can be changed by additional selective elements in the laser resonator – in this case etalons. The frequency locking by an electronic servo-loop is necessary in a real-time.

The laser linewidth reduction by etalons led to discontinuities in the laser tuning and detection of the Rb transition became impossible. With the presence of gas mixtures of certain pressures in the cell necessary for the spin-exchange process the linewidth of the absorption line in Rb will be significantly increased. In our first experiment we started with increasing of the cell pressure by He in the role of a buffer gas [2]. The optimum value of the He pressure ($1.16*10^5$ Pa) was calculated for the absorption linewidth 20 GHz at the temperature 373 K.

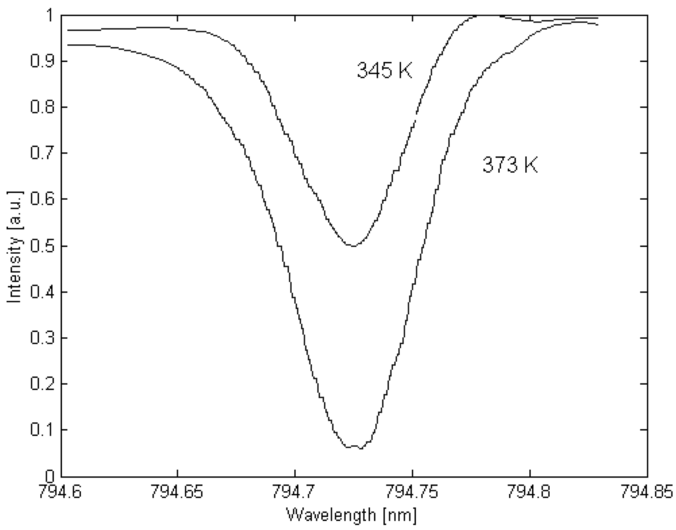

Fig. 2: *Experimental results of the Ti:Sa laser radiation in mixture of Rb and 3He measured by tuning of the laser*

For the frequency locking of the Ti:Sa laser, we employed a technique with wavelength modulation and the first harmonics detection. For these purposes we equipped a tilting micro-screw of the birefringent filter by a piezoelectric actuator - PZT.

The measurement of linewidth of the laser was based on the detection of contrast of interference fringes in a Michelson interferometer assembly. The coherence length was 12 mm which corresponds to the linewidth of 25 GHz.

The measured absorption line is in fig. 2. The absorption of laser radiation is close to 100 % at the temperature 373 K. After manual selection of the proper Rb transition, the servo-loop software allows stabilization of the Ti:Sa laser wavelength at the center of the absorption line of Rb transition.

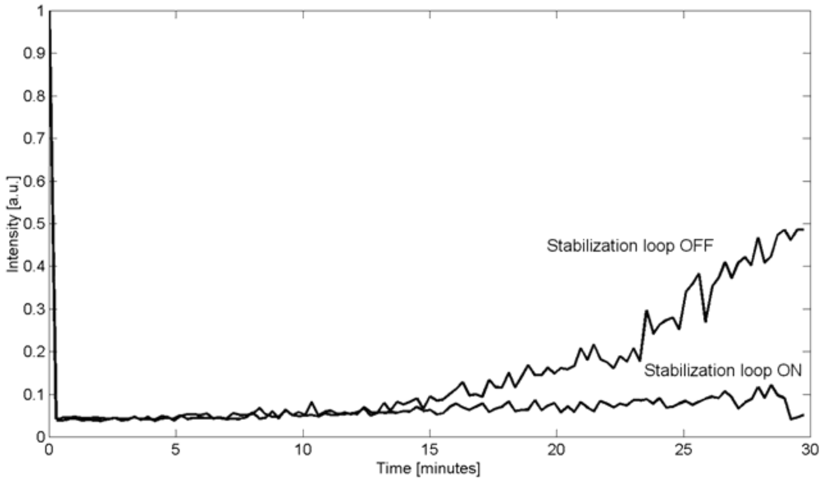

Fig. 3: *Illustration of the effect of using the stabilization loop*

4 CONCLUSION

We modified the commercial available Ti:Sa laser for the ability to automatic tuning by PC and AD/DA convertor. For control the tuning process was created the special software in LabVIEW programming system. The laser linewidth was determined by the coherence length measurement and the value is 25 GHz. For this value was calculated the optimal pressure of He ($1.16*10^5$ Pa at 373 K) for the collision-broadening of Rb absorption line. Thereafter the laser was used for optical pumping of the mixture of Rb and He. There was reached the optical pumping efficiency approximately 90 % at 373 K (fig. 2.). The stabilization loop for the frequency locking of the Ti:Sa laser on the top of absorption line was tested too (fig. 3.), but for the long-time stabilization we optimized and adjusted the regulator parameters.

ACKNOWLEDGEMENTS

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