HIGH-EFFICIENCY CONTINUOUS PRODUCTION OF HYPERPOLARIZED ^{129}XE USING LINE-NARROWED DIODE LASERS AND OPTIMIZED CELL FOR HIGH CONCENTRATION OF OPTICALLY PUMPED RUBIDIUM

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Introduction: The hyperpolarization of Xe gas is usually performed by the spin-exchange method [1]. A flow apparatus was developed and the polarization of Xe was performed under conditions including dilution by a He buffer gas [2]. Recently, a polarizer for large-scale production, applying pumping at a low pressure, was presented [3]. Here, we present a compact flow-through-type apparatus for the high-efficiency continuous production of hyperpolarized ^{129}Xe using line-narrowed diode lasers and an optimized cell for obtaining a higher rubidium vapor concentration at a higher temperature (~220 ^{o}C).

Method: In the flow-mode generation of a hyperpolarized noble gas, it has been difficult to increase polarization and the generation rate (flow rate) simultaneously. When the amount of light absorption is increased, the proportion of ineffective gas, which flows in the region with low light intensity, can be decreased by decreasing the optical-path length of the optical pumping cell. In other words, the generation efficiency of a hyperpolarized noble gas is increased by increasing the partial pressure of rubidium vapor, which absorbs the light in the flow apparatus. In our study on the structure of the pumping cell, the following conditions have been found to be essential for increasing the generation efficiency of the hyperpolarized noble gas: (1) using a flat flow cell with a thin gap, a mixture of the noble gas and vaporized rubidium is introduced into the flow cell along one direction; (2) excitation light is irradiated inside the flow cell and a magnetic field is created by placing a magnet in the flow cell in such a way that the lines of magnetic force are perpendicular to the surface of the flow cell; (3) linear laser diode arrays are used as light sources, and the arrays are arranged so that all the gas flowing through the cell passes through the region where the pumping light is sufficiently intense, as shown in Fig. 1.

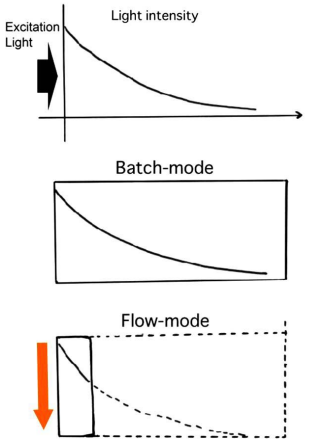

Fig. 1 Optimized cell structure for flow mode generation.

Experiments and Results: A flow-through-type apparatus for the polarization of ^{129}Xe using four line-narrowed high-power InGaAsP diode laser arrays (Coherent B1-79-40.0C-19-30-A), with fast and slow axis collimation lenses (Ingeneric) and a volume holographic grating (Ondax PowerLocker™, PLR794.5-22.5-13-1.75-1.5) (794.73 ± 0.15 nm, 40 W × 4 = 160 W) was constructed, as shown in Fig. 2. A mass flow controller (ESTEC, SEC-7330M, 100 sccm max) controlled the flow rates of 30% Xe (99.995%) and 70% N_2 (99.9995%) mixed gases. Rb metal (99.99%) (Furuuchi chemicals) was used. The mixed gas was introduced into a quartz cell (~ 50 mm × 70 mm × 1 mm) set at the center of the assembled permanent magnet, which contained holes for the laser beams to pass through, where the field is ~10 mT (NEOMAX). Rb metal was deposited on one side of the interior cell surface. The polarizing cell was heated in an oven maintained at a constant temperature using a heated-air blower (LEISTER). After passing through the gratings the beams were expanded using two sets of AR-coated cylindrical lenses to produce four beams superimposed on the thin cell gap, which then passed through λ/4 wave plates, (CVI, QWPO-795-10-4-R15). Hyperpolarized Xe gas was introduced into the 10 mmϕ NMR sample tube inside NMR probe along a silica capillary tube of internal diameter was ~ 0.53 mm (GL Science) inserted into the sample tube. The ^{129}Xe NMR spectra were measured using a Tecmag Apollo spectrometer equipped with a wide-bore 6.3 T superconducting magnet at a frequency of 74.7 MHz. The width of a 90^{o} pulse was 30 μs. To optimize the pumping conditions, the flow rate of the Xe and N_2 mixture gas was varied within the range of 5-100 sccm. The polarization rates of hyperpolarized ^{129}Xe were calculated using the accumulated thermally polarized ^{129}Xe NMR signal intensity. The obtained maximum polarization of ^{129}Xe for the natural abundance of Xe gas was 20 ± 5 % when the temperature of the cell was ~ 220 ^{o}C and the flow rate of the mixture gas was 40-100 sccm, as shown in Fig. 3.

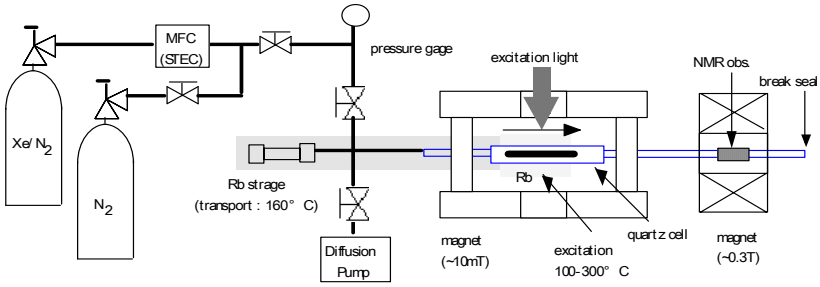

Fig. 2 Schematic of flow-through-type apparatus for HP Xe gas.

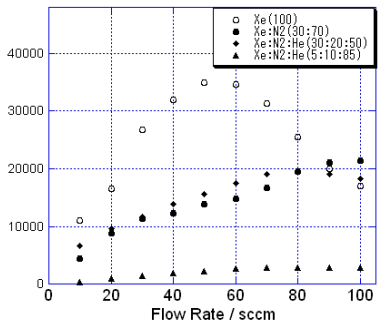

Fig. 3 Flow rate dependence of the ^{129}Xe NMR signal intensities.

Conclusion: We have developed a flow-through-type apparatus with a cell structure that is optimized for the hyperpolarization of ^{129}Xe. In this equipment, to increase the laser adsorption coefficient, heating temperatures in the polarization cell are set at 180 to 300 ^{o}C. Heating causes the vapor pressure of Rb to increase, and the irradiation cell gap is set at 1 mm, resulting in a polarization rate of ~ 20% and a high rate of polarization of ^{129}Xe per unit of time at a flow rate of 40-100 sccm. The flow-through-type production method overcomes the limitation of batch-type production [4], that is, the polarized ^{129}Xe depolarizes when it collides with the cell wall and/or other molecules. However, the newly developed equipment makes it possible to realize the continuous production of hyperpolarized ^{129}Xe with high productivity.

References:

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