薄膜アルカリ塩のスピン偏極と緩和

Spin polarization rise and decay in a thin film of alkali salt

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Introduction

The project aims to develop an universal method to hyperpolarize solids.

Optical pumping

- Electrons $\langle S_z \rangle$ and nuclei $\langle I_z \rangle$ of alkali atoms are polarized near the surface
- Random scattering medium
- Zeeman splitting
- Optical path length

σ_+ π σ_-

Spin injection at surface

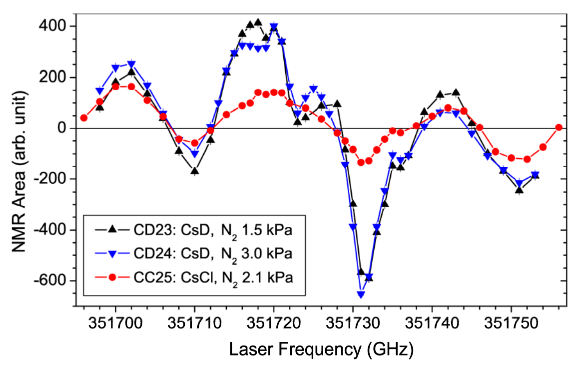
- Large surface area
- Nuclear spin polarization $\langle I_z \rangle$ are injected to salts

Glass Wool

Diffusion spin current

- Nuclear dipole interaction
- Spin diffusion length ~ Film thickness

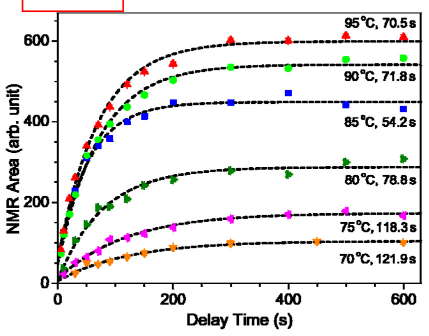
Enhancement Spectrum



NMR enhancement was measured by scanning laser frequency for CsD salt (▲ and ▼) and CsCl salt (●). The identical spectral shape indicates that the nuclear spin polarization of Cs atoms were injected into the salts.

Saturation Recovery

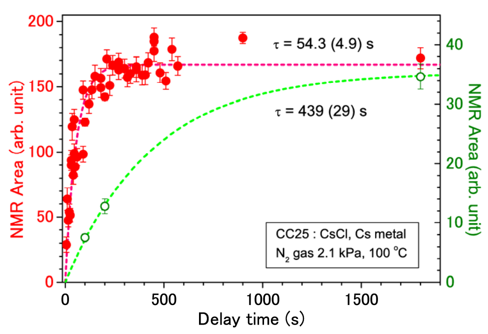
CsD



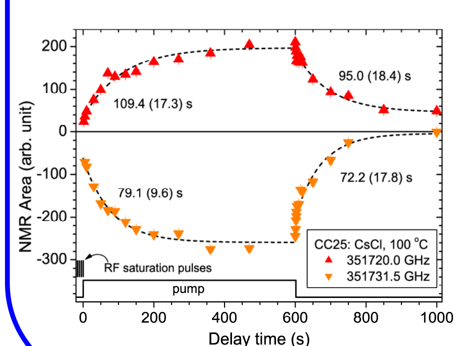
Saturation recovery of spin polarization of CsD at the respective temperatures. See figure on "Curing of Alkali Salt Cell" for the steady-state amplitude. The optimum amplitude was obtained at 95 ℃. See figure on "Decay Rate" for the time constant of recovering.

CsCl

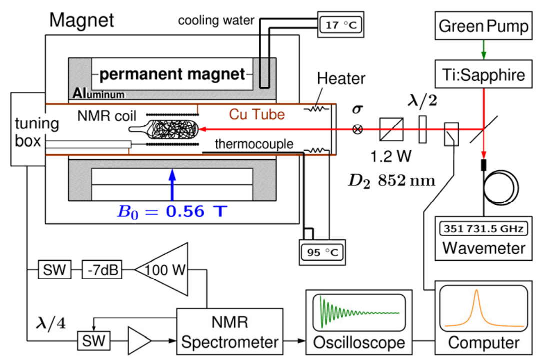
Saturation recovery of enhanced (●, left vertical axis) and thermal (○, right vertical axis) signals for CsCl at 100 ℃. The time constant of buildup are different between these signals. It indicates that the salt presenting enhancement is different from that for thermal signals.



Spin buildup and decay behaviors for CsCl at 100 ℃. The bottom inset shows that the saturation RF pulses initialized the spin polarization at t=0. The glass cell was irradiated with pump light for 600 s. Dotted curves are the best fit of a single exponential curve. The similar time constants were obtained in both dark and illumination.



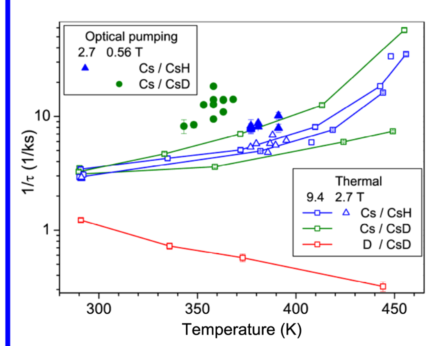
Experimental Setup



CW pumping light was linearly polarized and routed into a permanent magnet. Cylindrical cell was filled with glass wool. Free-induction decay of Cs salts was detected by a solenoid coil. NMR Trace was Fourier transform of the transient signal.

Decay Rate

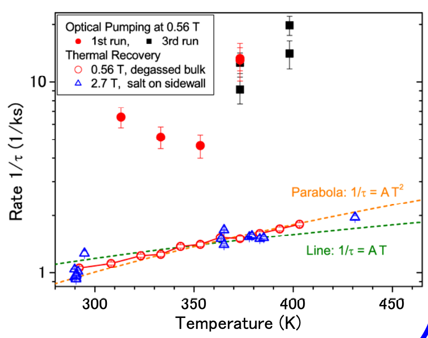
Thermal and enhanced signals of CsH and CsD



The decay rate of optically enhanced signals (●) was larger than the thermal ones. The decay rate increases for Cs (□ and □) and decreases for D (□) as heating. The temperature dependence is super-exponential and it indicates that the hydride is dissociative.

Thermal and enhanced signals of CsCl

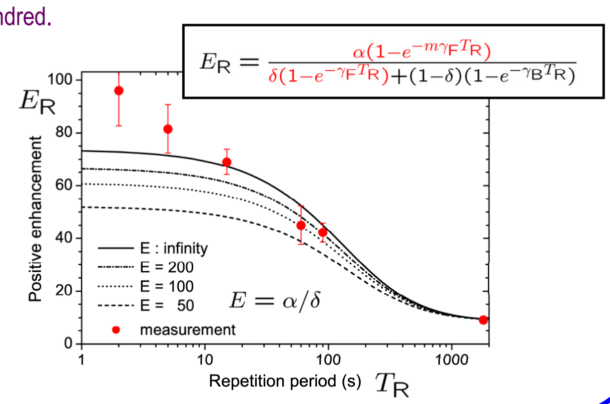
The decay rate of optically enhanced signals (● and ■) was much larger than the thermal ones. The decay rate for thermal signals (○ and △) was increases as heating. The temperature dependence indicates that the spin relaxation is due to the Raman process of phonon scattering.



Real Enhancement

The ratio of enhanced and thermal signals was measured by changing the repetition period of RF excitation pulses. The T_R dependence shows that the enhancement of CsCl film surpassed a hundred.

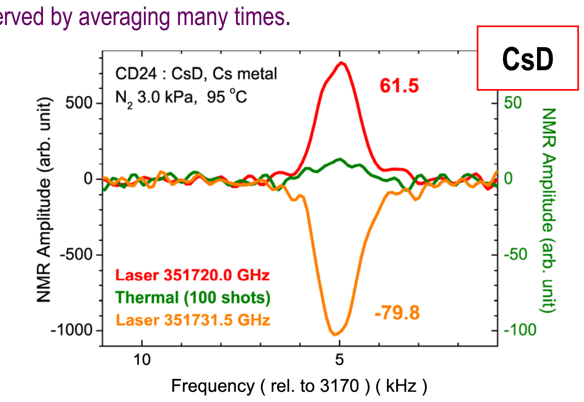
$$E_R = \frac{\alpha(1-e^{-m\gamma_F T_R})}{\delta(1-e^{-\gamma_F T_R})+(1-\delta)(1-e^{-\gamma_B T_R})}$$



NMR Enhancement

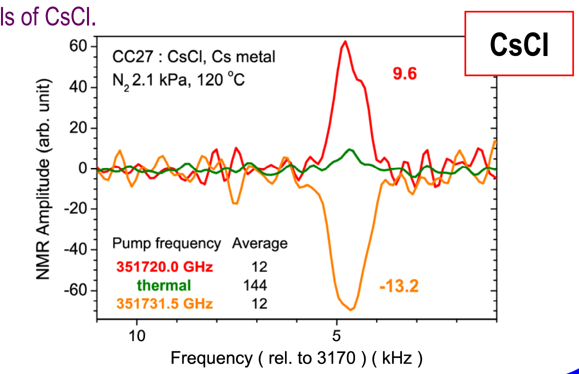
NMR signal was positively or negatively enhanced by optical pumping at each laser frequency. The amplitude was so large to measure by a single shot. On the other hand, thermal signal was observed by averaging many times.

CsD



Thanks to glass wool, we could detect and also enhance NMR signals of CsCl.

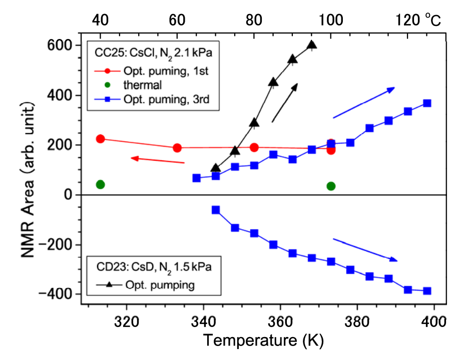
CsCl



Curing of Alkali Salt Cell

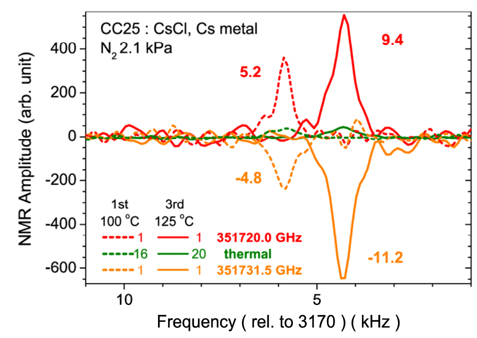
Temperature dependence of NMR enhancement

During the first run after manufacturing (●), signal amplitude of CsCl was independent of temperature. By curing (■), the amplitude increased as heating as expected from the atom density. The signal of CsD depended on temperature at the first run.



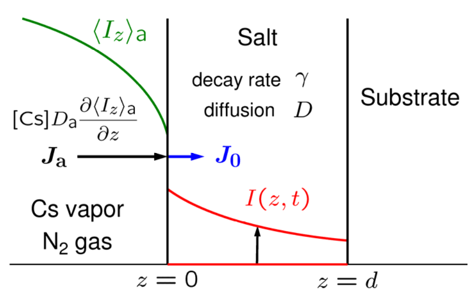
NMR enhancement improved by the curing

NMR enhancement was improved by the curing procedure that the excess Cs metal was removed from salt surface by the flame heating.



Thin Film Model

Nuclear spin polarization $\langle I_z \rangle_a$ of atomic vapor is injected to the homogeneous film though the surface on xy plane. The initial condition is $I(z, 0)$=0 shown by red horizontal line. The diffusion spin current transmit through the both surfaces at z=0 and z=d.



Buildup rate, Signal amplitude, and Optical enhancement are calculated at each film thickness. The rate for thin film is larger than the bulk salt though the absolute amplitude is never enlarged.