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7.13 Hyperfine Interactions of Spin Polarized β-Emitter ^{12}N in Fe Crystal

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Hyperfine fields detected by dilute ^{12}N impurity at the interstitial sites of ferromagnetic Fe were studied as well as its lattice distortion due to the impurity. The technique employed here was essentially the same with that used in the previous works[1,2], i.e. the NMR detection in which the asymmetric β decay from the polarized $^{12}N(I^{\pi}=1^{+}, T_{1/2}=11 ms)$ nuclei was monitored[3]. Nuclear spin polarized ^{12}N was obtained at recoil angle $\phi = 15\sim25$ degrees in $^{10}B(^{3}He,n)^{12}N$ reaction initiated with ^{3}He ions of 3.0 MeV. The polarization detected in the β-decay asymmetry was P = 0.25. The angular distribution of the β-ray is given by $W(\theta) = 1 + P\cos\theta$ where θ is the polar angle of β-ray momentum relative to the polarization direction. A strong magnetic field H_0 was applied parallel to the polarization for the purpose of the NMR detection, which field was also very effective to maintain the polarization during the flight of the ^{12}N ions in vacuum before they reached an implantation material. The ions ejected from the target were embedded (implanted) in Fe crystal by use of the kinetic energy obtained in the nuclear reaction. Because of the heterogeneous energy spread due to the target thickness of about 100 μg/cm^2 and the spread in the recoil angle, the distribution of ^{12}N ions in the sample was almost even throughout the region from the surface to the maximum recoil range. Since the estimated density of ^{12}N was very dilute, $\sim10^{10}$ /cc, only the interaction of the present ^{12}N impurity with host atoms were studied, in other words, the interaction with other ^{12}N impurities themselves was negligible.

A typical NMR spectrum, the polarization change, as a function of rf frequency at H_0 = 7 kOe and T = 120 K, is shown in Fig. 1. The crystal axis <011> was set parallel to H_0. The observed field consisted of five components,

$$\vec{B}_{obs} = \vec{B}_{ext} + \vec{B}_L + \vec{B}_{DM} + \vec{B}_{hf} + \vec{B}_{dip} + \vec{\omega}_Q/\gamma,$$

where B_i in the right hand side are external magnetic field, Lorentz field, demagnetization field, hyperfine field, and dipolar field. ω_Q is the angular frequency due to the nuclear quadrupole interaction. Since B_L and B_{DM} are estimated from the known magnetization of Fe at temperature T, i.e. $M_s(T)$, and also ω_Q is measured in the experiment ($B_{hf} + B_{dip}$) is easily determined from the NMR spectra.

From the NMR spectra as a function of crystal orientation relative to H_0, two locations were determined. For the resonance line at 1.9 MHz, B_{dip} due to the possible anisotropic distribution of surrounding Fe atoms around an interstitial ^{12}N is deduced to be $B_{dip}\sim 0$. Also this was well explained by two lines split due to the quadrupole interaction of $\omega_Q/2\pi = 0.75eqQ/h$ = 400 kHz. The lines are from ^{12}N in an interstitial site. Experimental hyperfine field due to the contact interaction of ^{12}N nucleus with conduction electrons of S-symmetry, $B_{hf} = -(9.41\pm0.11)$ kOe was obtained. For the resonance at 3.7 MHz, finite amount of dipolar field $B_{dip}\sim\pm2$ kOe was observed, and the hyperfine field of -35 kOe $< B_{hf} <$ +20 kOe was determined. In spite of the appreciable amount of B_{dip}, we could not extract it clearly neither determine the location of ^{12}N from this. The sign of B_{hf} was not also determined because of the unresolved B_{dip} and ω_Q. Although, we can conclude that the locations are interstitial, exact sites were not determined. However, those observed B_{hf} values are extraordinary small compared with theoretical one based on ab initio band calculation[4] for ^{12}N ions in tetrahedral and octahedral sites by J. Kanamori et al., i.e. $B_{dip}\sim -70$ kOe. If, in this powerful theory, the lattice renormalization (expansion) of about $\Delta a/a$ = 50 % for, at least, the nearest surroundings, which was observed for ^{12}N in V crystal[3] taken into account, a better agreement in the experimental and theoretical values will be obtained. It is also pointed out in this hyperfine interaction studies of ^{12}N in Fe that they are implanted in two independent interstitial sites. This shows a strange deviation from the systematics on ^{12}N ions in other crystals that they are located in an interstitial site.

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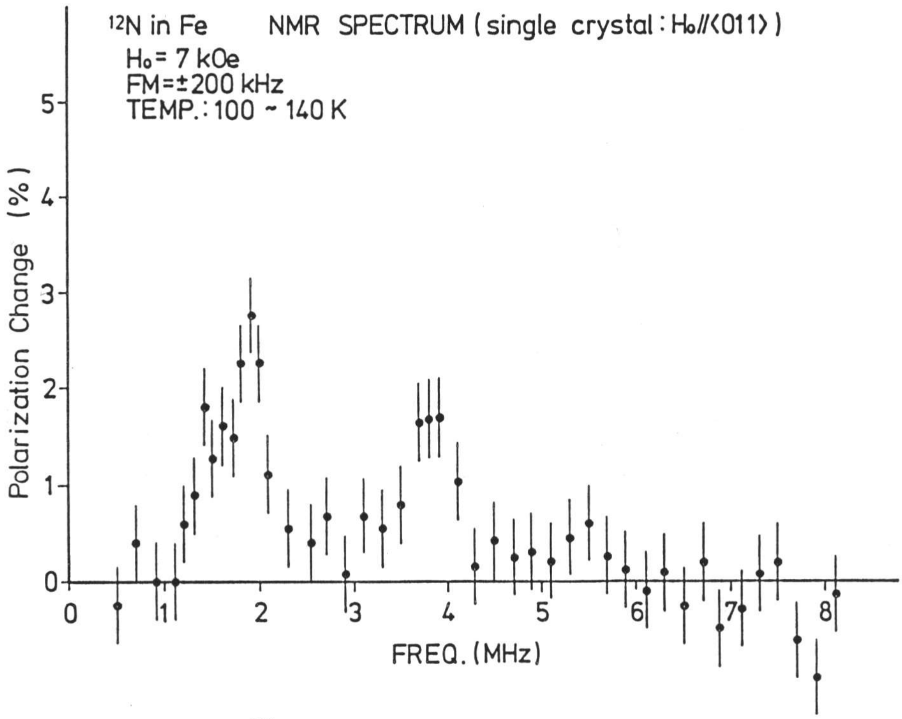

Fig. 1. NMR spectrum of ^{12}N in ferromagnetic Fe.
The crystal axis <011> of Fe was parallel to H_0 of 7.0 kOe at T = 120 K.