

The study of Co/Cu multilayers by NMR method

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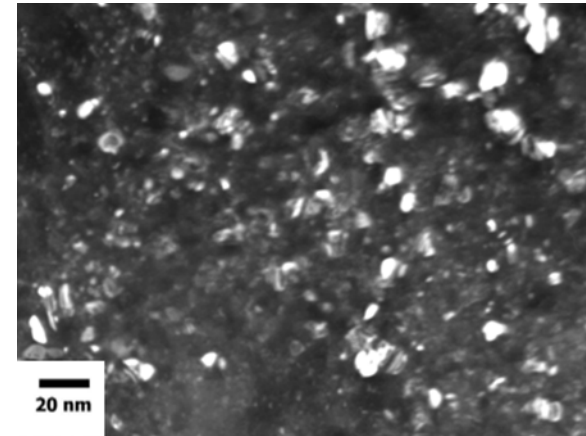
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The Samples

- $[d_{Co}/d_{Cu}] \times 100$ multilayers;
effective Co layer thickness $d_{Co} = 3.5 \text{ \AA}$,
 $d_{Cu} = 1.5 - 30 \text{ \AA}$,
multilayers with different d_{Co} also have been examined.
- Sputtering conditions:
DC magnetron sputtering
Base pressure $\sim 10^{-6}$ Torr
Working pressure of Ar 2×10^{-4} Torr
Glass substrates

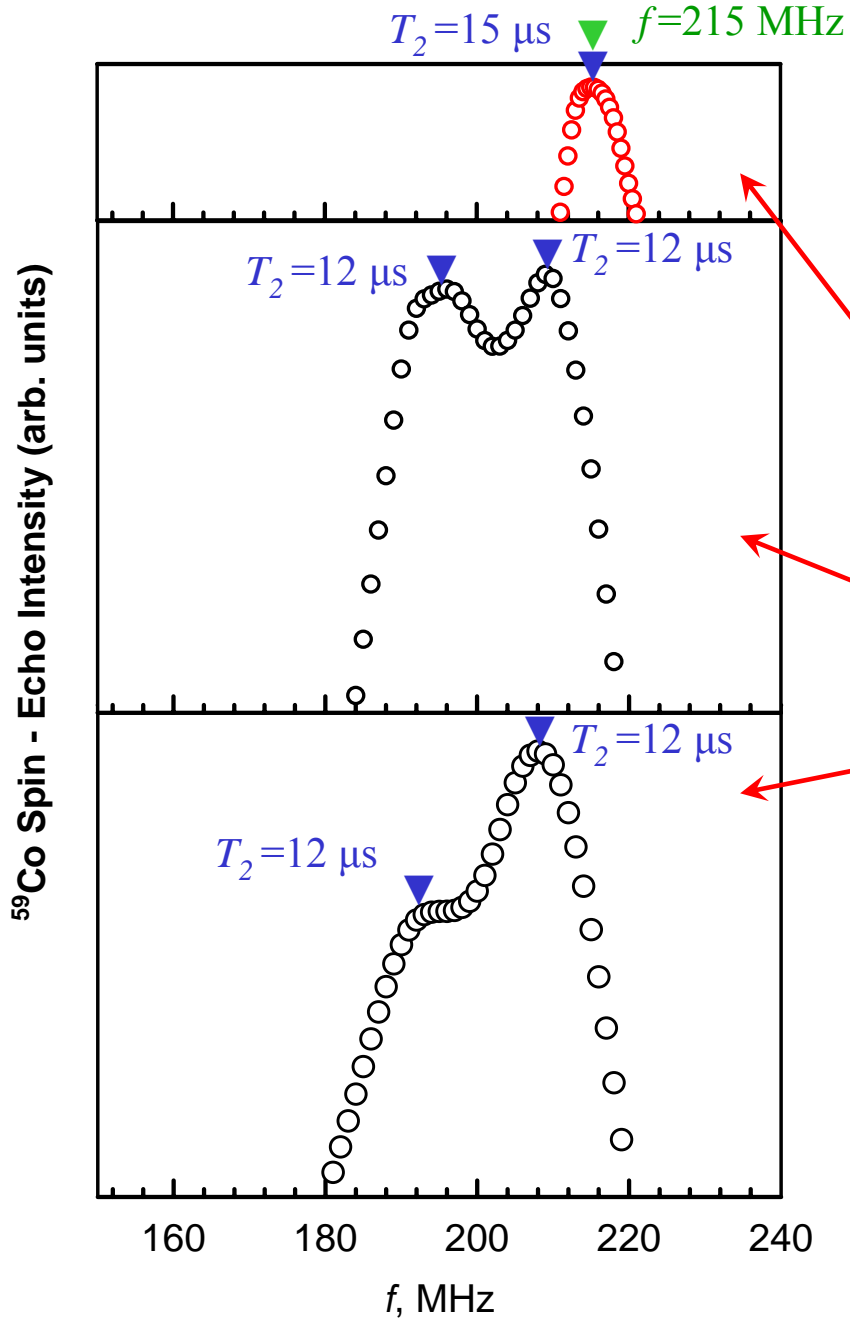
Sample Structure

- All samples have *fcc* lattice structure
- The lattice parameter measured from TEM experiments changed linearly with d_{Cu} growth reaching the lattice parameter of bulk Cu at $d_{Cu}=8 \text{ \AA}$
- TEM images shows the polycrystalline structure of the samples with the grain size distribution from the very small $\sim 15 \text{ \AA}$ to 100 \AA
- No cross-section data



Dark-field image for
3.5 \AA Co/6 \AA Cu sample

NMR spectra of the samples with $d_{Co}=3.5 \text{ \AA}$



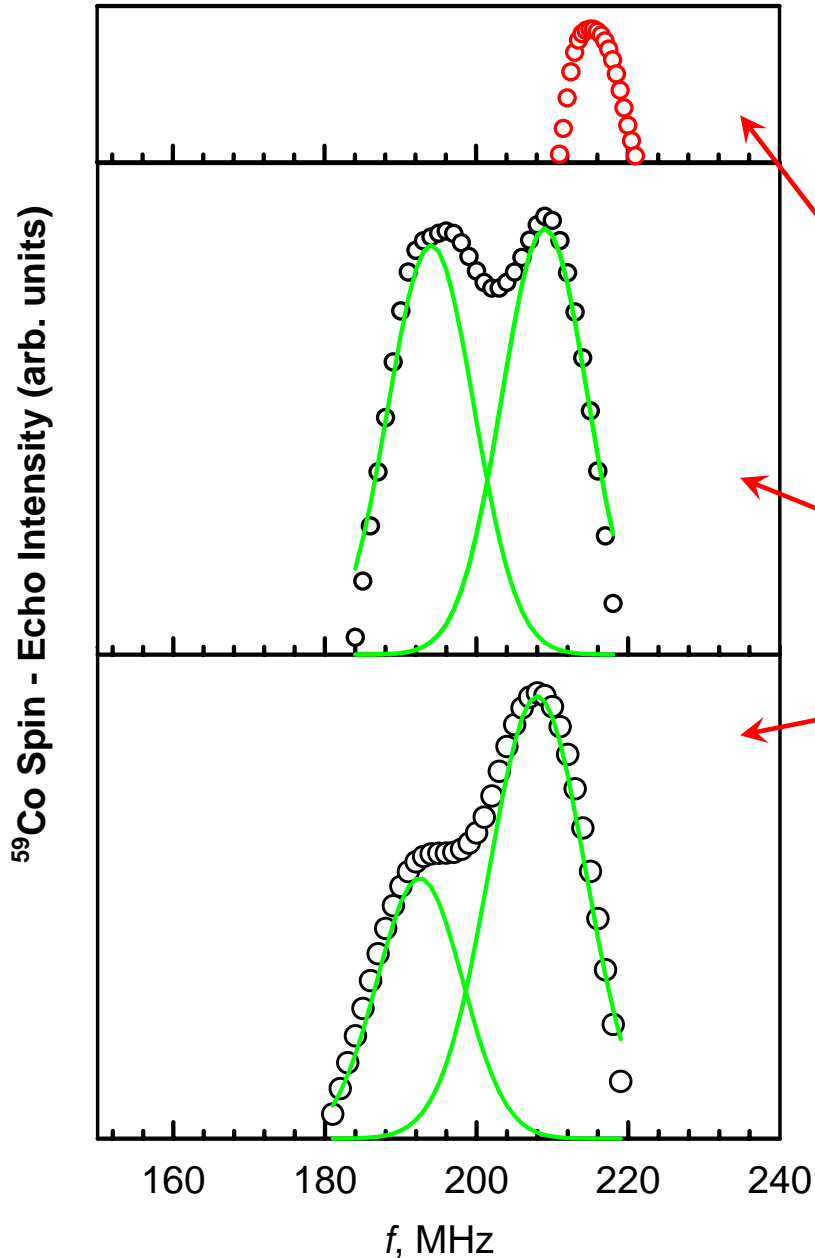
The film of pure Co sputtered at the same conditions as multilayers

3.5 Å Co/1.5 Å Cu

3.5 Å Co/2 Å Cu

In case of $d_{Cu} > 2 \text{ \AA}$ (effective Cu layer thickness) the spin-echo signal was not detected

NMR spectra of the samples with $d_{\text{Co}}=3.5 \text{ \AA}$



The film of pure Co sputtered at the same conditions as multilayers

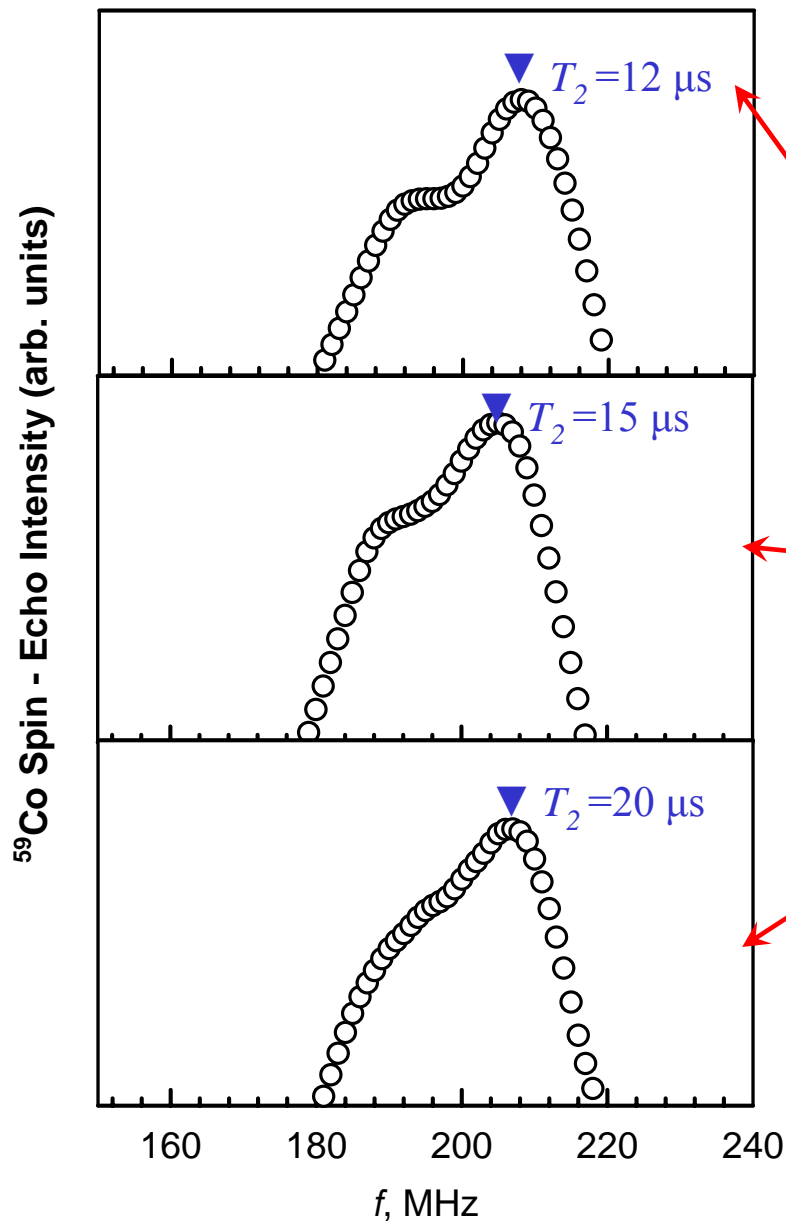
3.5 Å Co/1.5 Å Cu

3.5 Å Co/2 Å Cu

$f_1=192 \text{ MHz}$

$f_2=208 \text{ MHz}$

Changing of NMR spectra of the 3.5 Å Co/2 Å Cu sample with aging



as prepared

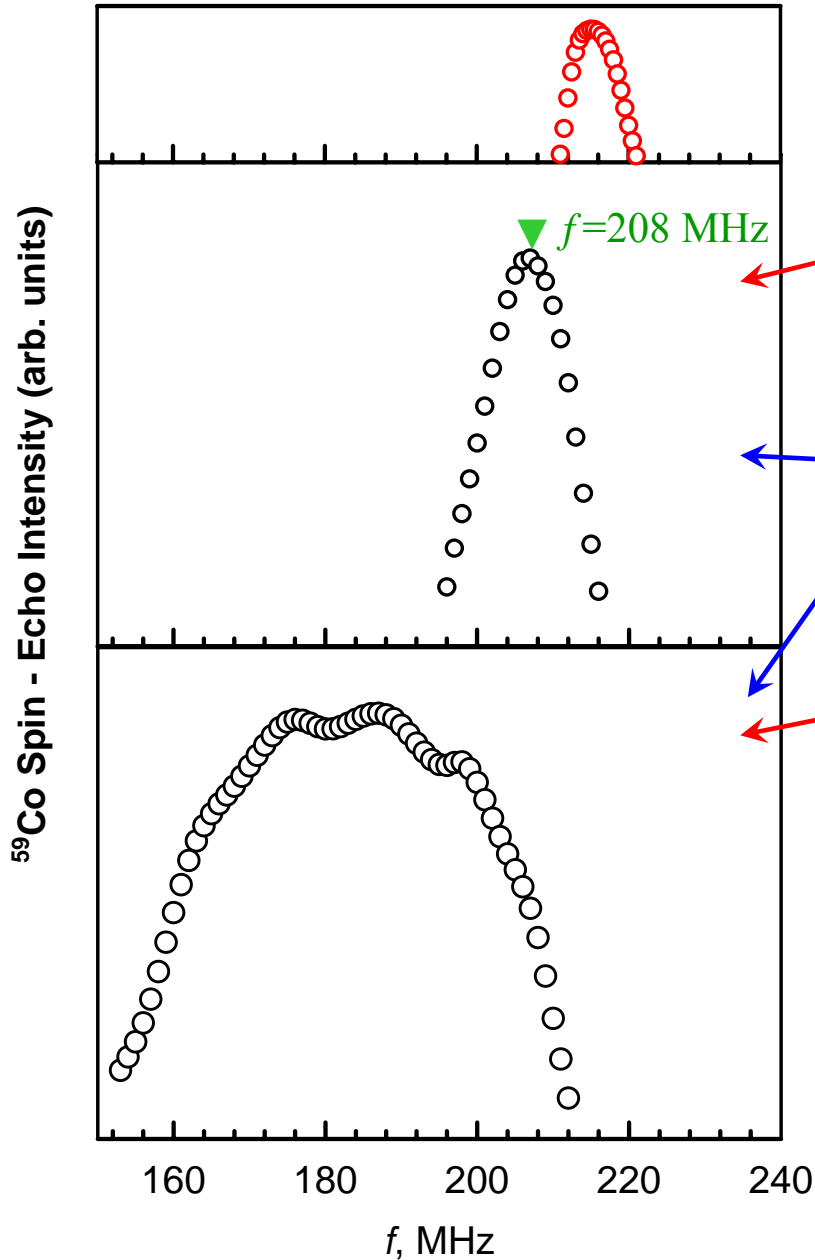
1.5 months later

2 years later

The possible reasons of the absence of spin-echo signal for the 3.5 Å Co/ d_{Cu} samples with $d_{Cu} > 2$ Å

- More homogeneous Co-Cu alloy forms where at least four Cu atoms in the nearest-neighbor shell are presented leading to the shift of NMR spectra into the low frequency region beyond to the sensitivity of NMR spectrometer;
- The magnetically hard phase forms. In this case the actuating signal amplitude and pulse duration used in the experiment are not sufficient for excitation of spin-echo signal;
- The spin-spin relaxation time decreases drastically with d_{Cu} increasing.

NMR spectra of the samples with $d_{Co}=2.5 \text{ \AA}$



2.5 \AA Co/0.8 \AA Cu

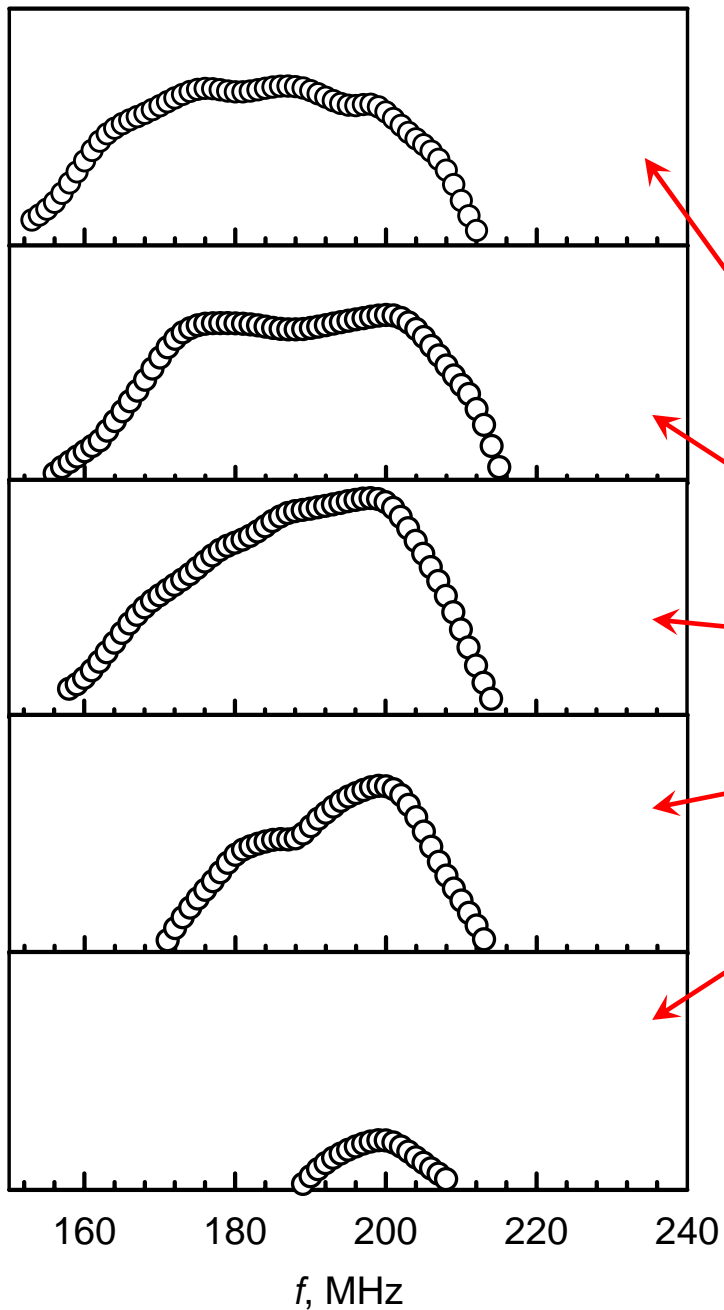
Spin - Spin Relaxation Time, $T_2 = 12 \mu\text{s}$

2.5 \AA Co/2 \AA Cu

In case of $d_{Cu} > 2 \text{ \AA}$ (*effective* Cu layer thickness) the spin-echo signal was not detected

Changing of NMR spectra of the 2.5 Å Co/2 Å Cu sample with aging

^{59}Co Spin - Echo Intensity (arb. units)



as prepared

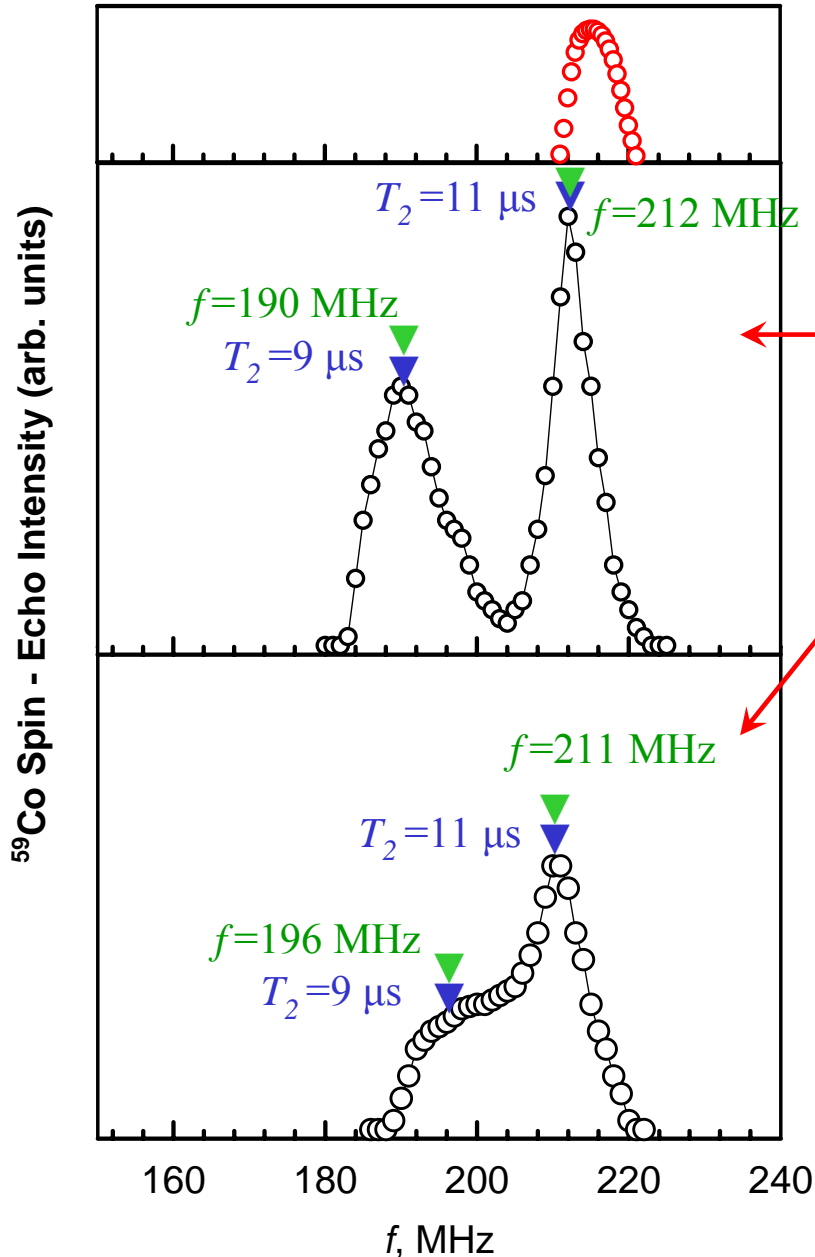
50 days later

2.5 months later

10 months later

2 years later

NMR spectra of the samples with $d_{\text{Co}}=4.5 \text{ \AA}$

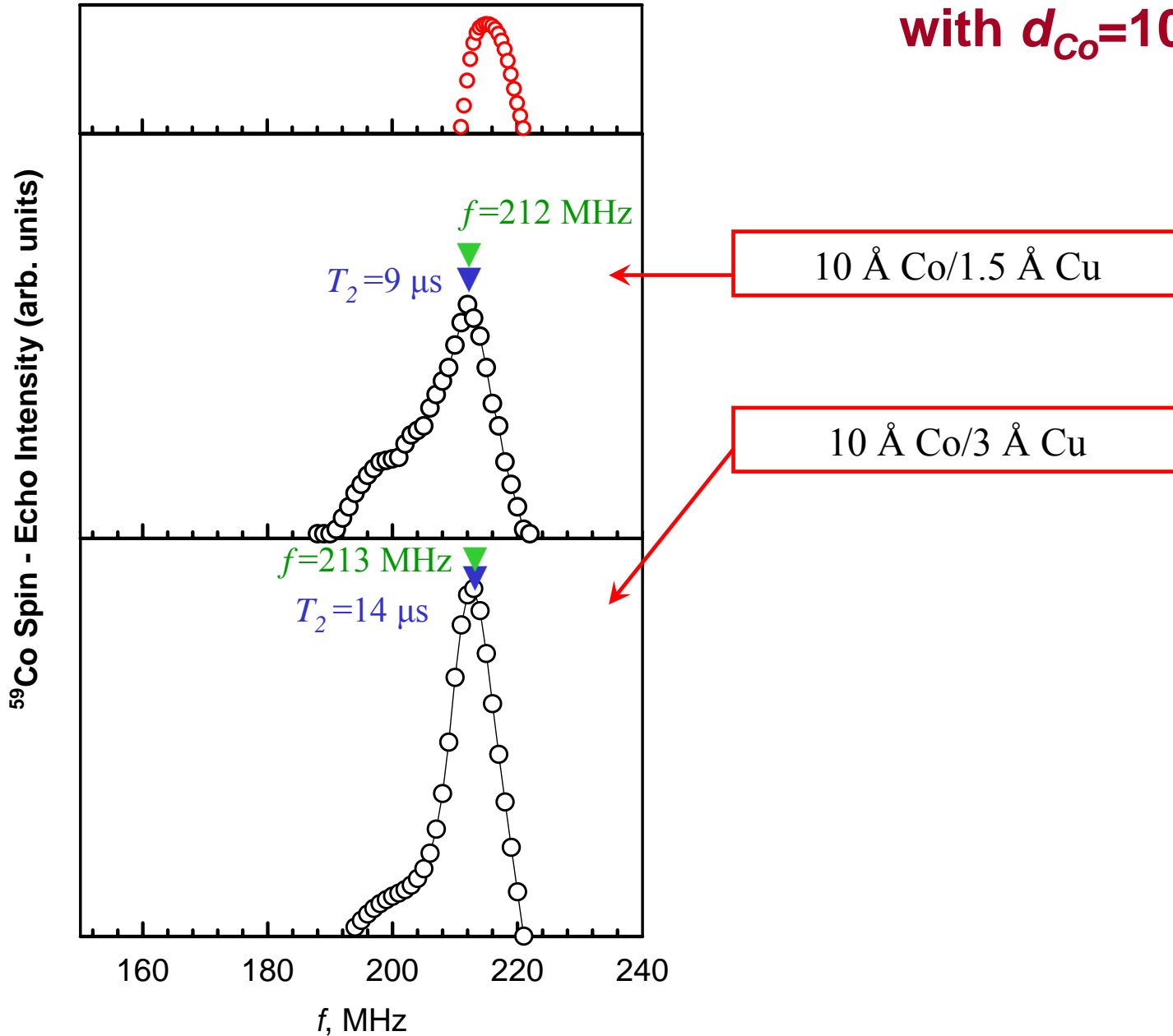


4.5 \AA Co/1.5 \AA Cu

4.5 \AA Co/3 \AA Cu

For the 4.5 \AA Co/6 \AA Cu sample the spin-echo signal was not detected

NMR spectra of the samples with $d_{\text{Co}}=10 \text{ \AA}$



Conclusions

- Investigation of Co/Cu multilayers with ultrathin magnetic layers ($d_{Co}=3.5 \text{ \AA}$ and more) by NMR method shows that cobalt is just slightly intermixes with copper, but influence of copper gives rise to the increasing number of the structure defects like strains etc. and to the visible shift of resonance lines into the low – frequency region.
- By sputtering of very thin layers Co and Cu it is possible to obtain the Co-Cu alloy even; this alloy is metastable and has a tendency to decomposition.

Thank you for your attention!