Measuring the pinning strength of SRF materials with muon spin rotation

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Muon production and decay

Positive muons are produced with 100% spin polarization with kinetic energy of 4.1 MeV.

Muons are deposited ~100 micron deep in a sample (bulk probe) – spin precesses with frequency dependent on local magnetic field.

Muon decays in $\tau_{1/2}=2.2\mu$sec - emits a positron preferentially along the $\mu^+$ spin direction.

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]

Muons are 100% spin polarized with kinetic energy of 4.1 MeV.

\[ \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \]
Muon Spin Rotation – muSR

- Muons are deposited one at a time in a sample
- Muon decays emitting a positron preferentially aligned with the muon spin
- Right and left detectors record positron correlated with time of arrival
- The time evolution of the asymmetry in the two signals gives a measure of the local field in the sample

\[ a_0 P_y(t) = \frac{N_L - N_R}{N_L + N_R} \]
Magnetic Volume Fraction

- Uniformly weakly magnetic
- Non-magnetic with magnetic impurities
- Static distribution of random fields

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Using muSR as local magnetometer

- A sample is cooled in zero field - asymmetry measurements are taken as a function of applied magnetic field
- The relative asymmetry at t=0 gives a measure of the volume fraction sampled by the muons that does not contain magnetic field
- A variety of samples and sample geometries have been characterized in this way

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The field of first entry and the role of pinning in different geometries

a) Ellipsoids and flat coin samples can be used

b) If the field is applied transverse to the sample surface it will first penetrate at the edges. Pinning will then delay the flux entry to centre which is the region probed by muSR

c) Applying the field parallel to the sample surface or using ellipsoids reduces the sensitivity to pinning

\[ H/H_0 \]

Most sensitive to pinning

\[ H_0 : \text{Expected field of first entry determined by generic } H_{c1} \text{ of niobium and demagnetization factor of the samples} \]
The field of first entry and the role of pinning in different geometries

- Ellipsoids and flat coin samples can be used
- If the field is applied transverse to the sample surface it will first penetrate at the edges. Pinning will then delay the flux entry to the centre which is the region probed by muSR
- Applying the field parallel to the sample surface or using ellipsoids reduces the sensitivity to pinning

The parallel field configuration is used to determine the field of first entry
- Measurements in transverse geometry measure the pinning strength
- We can measure pinning strength and field of first entry of one sample using both geometries
Bulk and surface treatments

1400C virtually eliminates all pinning
Here $H_{\text{entry}}$ is equal for all geometries

800C baking: still fairly strong pinning

Forming increases pinning
A 1400C bake virtually eliminates it completely

Surface treatments like BCP do not change the pinning strength of annealed samples
Summary

• Pinning is an important parameter for SRF since it can prevent flux expulsion during cooldown of cavities.
• We have developed a way to use muSR to measure the field of first entry and the pinning strength of SRF materials.
• Bulk pinning in the material changes considerably depending on the bulk and surface treatments.
• A 1400C heat treatment virtually eliminates pinning and surface treatments like BCP do not erase the effect.
• However a sample with strong pinning can have the pinning enhanced with BCP and 120C bake.