Raman Spectroscopy as a Probe of Surface Defects in Nb for SRF Cavities

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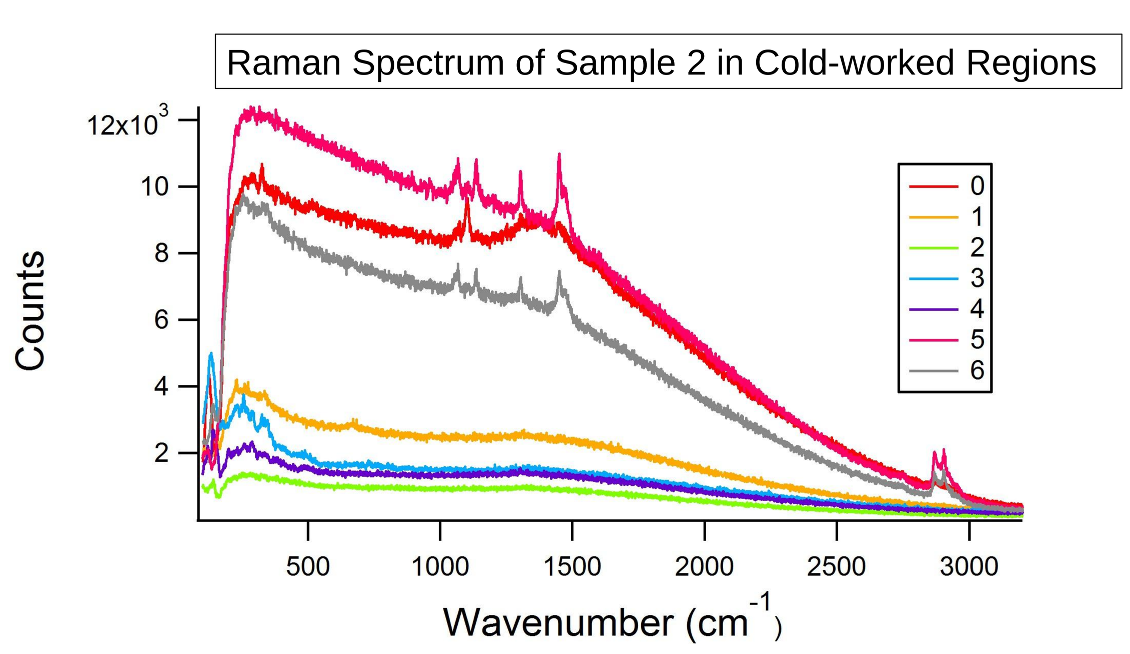
Introduction

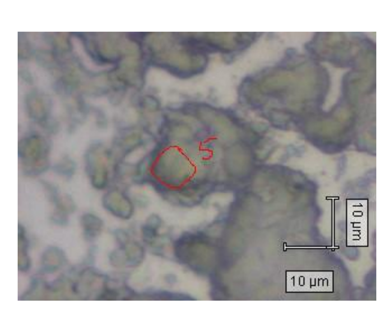
Superconducting RF (SRF) cavities made of Nb are an enabling device for future linear accelerators. Recently it has been demonstrated [1] that hot spots in SRF cavities, which diminish performance, are correlated with a high density of defects (etch pits) especially near grain boundaries. For a pit to cause local heating, it is likely that near-surface impurities, e.g. hydrides or oxides are leading to suppressed superconductivity. New probes are needed to measure such complexes. Here we present Raman spectroscopy. Raman is a fast, nonperturbative method that can measure the vibrational modes of Nb-O and Nb-H complexes by inelastic light scattering. These can then be compared to molecular dynamics simulations to identify oxide and hydride phases. The probing depth of Raman is estimated from the skin depth of the 785 nm laser in the bulk Nb ~ 10-20 nm. This is a reasonable fraction of the superconducting penetration depth ~ 45 nm.

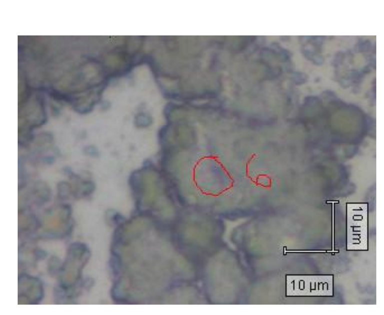
Simulating manufacturing processes of SRF cavities may shed light on the origins and composition of hot spots, and their relationship with defects in the material. Defects such as pits, whose origins are yet unknown, are found in the hot spots of completed cavities. Raman spectroscopy is used here to identify changes in the surface chemistry after manipulations such as creating artificial pits, exposing the material to chemical etching, or cold-working the material. BCP exposure and cold-working are common to the SRF manufacturing process.

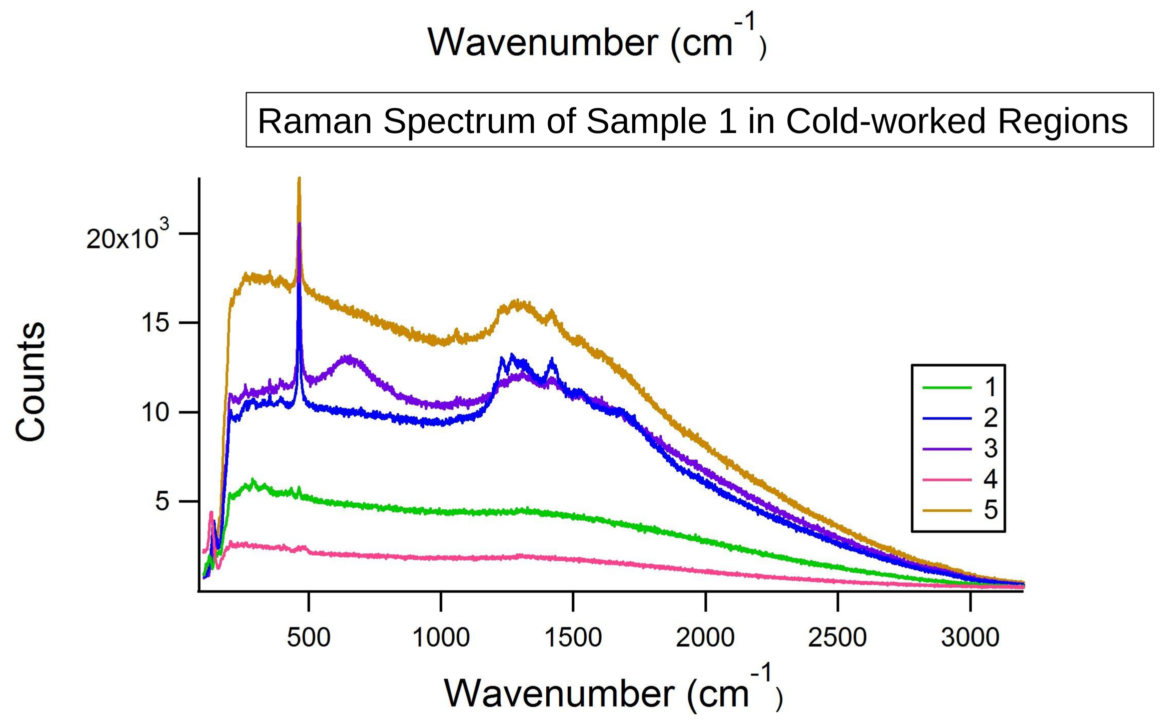
Cold-Worked Regions

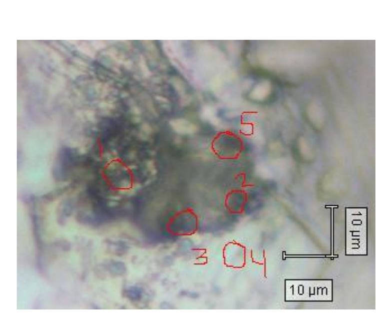
Cold-working was done on two Nb foils which had been previously exposed to BCP. The foils were bent at 90° angles about 50 times, creating a rippled texture on the surface. Raman spectroscopy measurements were done in the rippled region and compared to measurements done in the unbent regions.



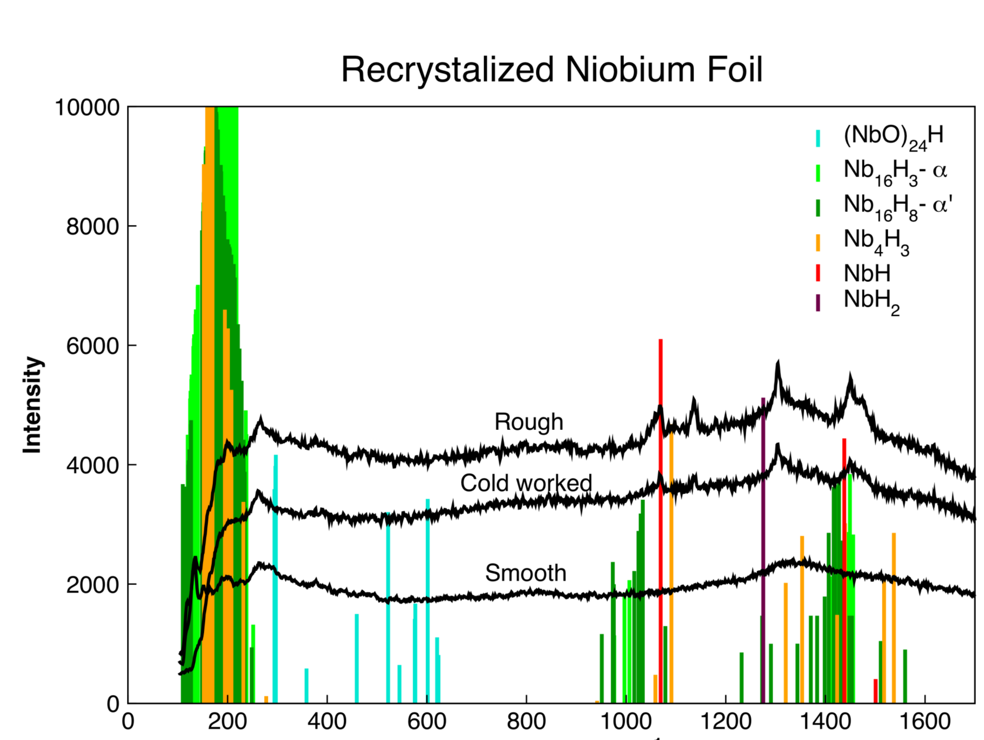




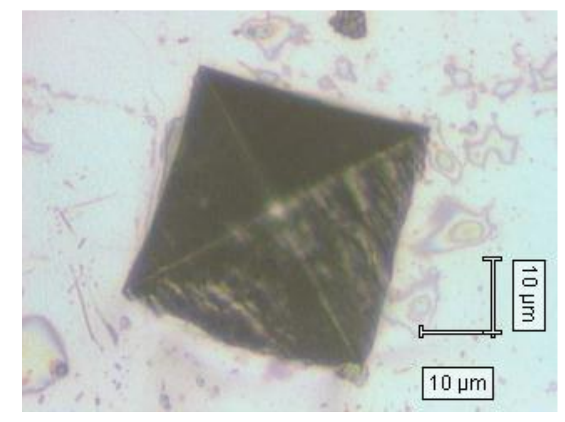




Previous results show rough spots on Nb foils always display Raman peaks in the range 1000-1600 cm^{-1} which are due to Nb-H complexes. Ordered hydrides (e.g. NbH) are found in cold worked (bent) foils as well.

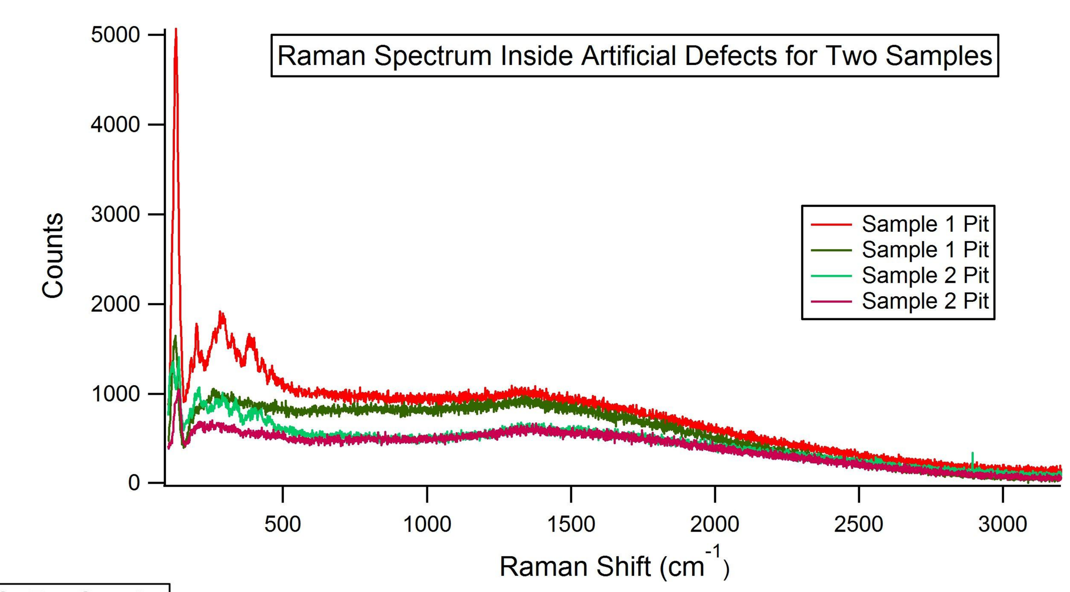


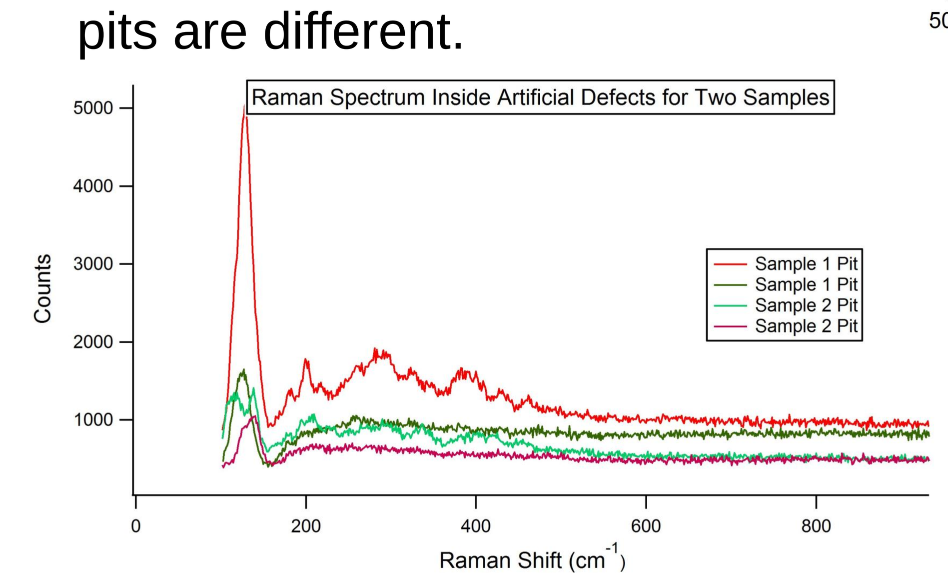
Artificial Defects



In an attempt to simulate natural defects, artificial pits were manufactured using a diamond tip. Regular indentations were made on the surface of a Niobium foil.

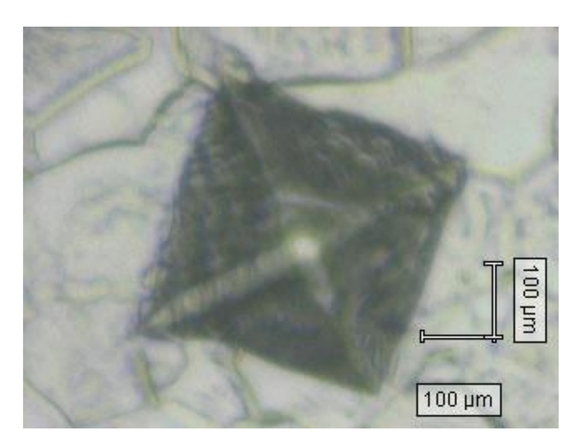
No significant peaks were seen in high wavenumber regions where the existence of hydrides would be signaled. Thus natural pits are different.



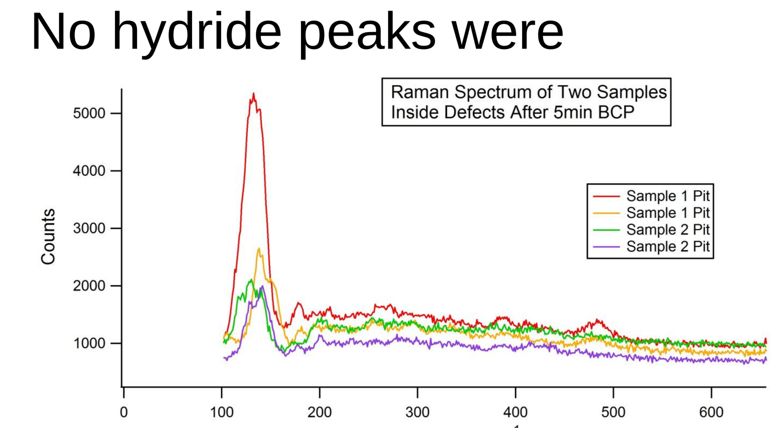


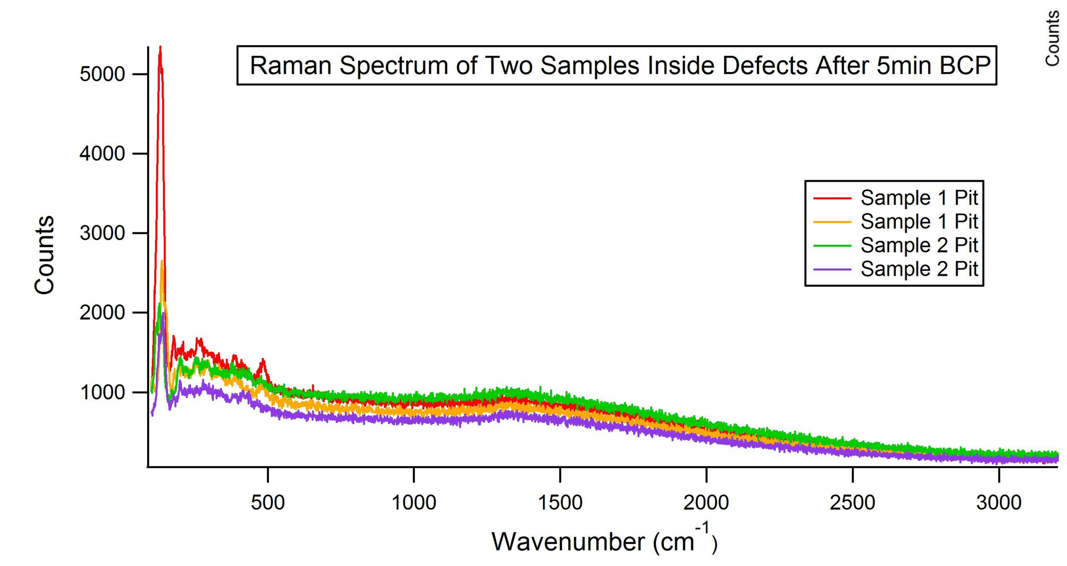
A closer look at small wavenumber reveals additional structure. These structures are sometimes seen on natural pits and we are in the process of identifying them.

BCP



Samples with artificial pits were exposed to 5 minutes of buffered chemical polish (BCP), and Raman Spectroscopy was performed in and around the pits. No hydride peaks were observed.





Conclusion

Raman spectroscopy has emerged as a highly useful tool to probe the Nb surface. Naturally occurring rough spots (pits) and cold-worked regions of Nb foils reveal ordered hydride phases in the Raman spectra indicating that dislocations attract hydrogen. This may explain why pits are associated with hot spots of cavities. Naturally occurring pits may be a signature of underlying dislocations which trap impurities and diminish the local superconductivity.

Artificial pits formed by the diamond tipped hardness tester did not reveal hydrides even after BCP etching. This may indicate that it is not simply the cavity that is attracting impurities, but rather underlying defects in natural pits. SRF cavities require a significant amount of processing, including deep drawing and forming. This may be similar to the cold working done here on foils.

References

[1] Xin Zhao, G. Ciovati and T.R. Bieler, Phys.Rev.STAB 13, 124701 (2010)

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