4-12-2019

Effects of Columnar Defects on Microwave Nonlinearity in a Superconducting YBCO Resonator

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Introduction

Timed measurements of second and third order intermodulation (IM) in two YBCO superconducting hairpin resonators were used to determine the effects of engineered defects on microwave nonlinearity. The defects consist of columnar channels perpendicular to the transmission line of each resonator and serve as pinning centers for trapped magnetic flux. Pinning is connected to nonlinearity, which can be measured as the strength of IM produced in each sample. Tests were performed by measuring the time dependence of the level of IM before, during, and after the application of a static magnetic field. Relaxation occurs after removal of the field.

Motivation

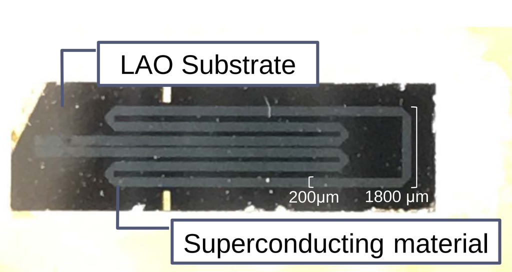
Superconducting electromagnetic resonators are used in a range of industrial and scientific applications:

- MRI pickup coils
- Wireless transceiver filters (for use in cellular networks)
- Radio telescope components

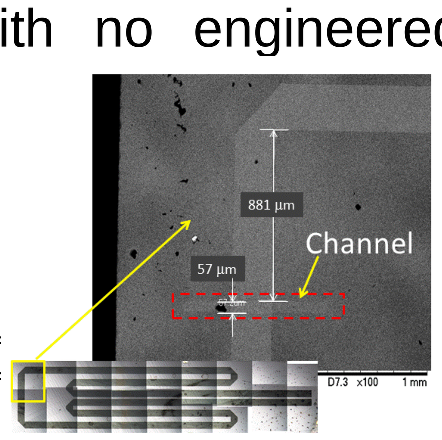
Understanding and controlling the mechanisms of signal distortion in these devices will allow for more effective and compact designs.

Devices Under Test

- DUTs are two thin film hairpin YBCO electromagnetic resonators with roughly identical dimensions and compositions.
- The test sample was irradiated with a beam of 250 MeV Au ions to create a channel of columnar defects perpendicular to the transmission line.
- Measurements on a control sample with no engineered defects were taken for comparison.

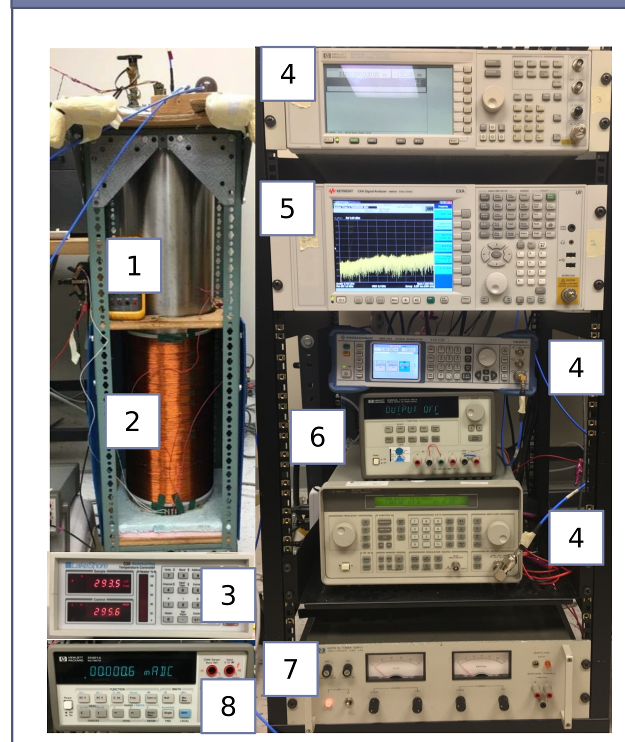


Photograph of the test sample. The control sample has the same layout and dimensions.



Polarized light microscope image of the test sample. The channel of columnar defects is highlighted.

Experimental Setup

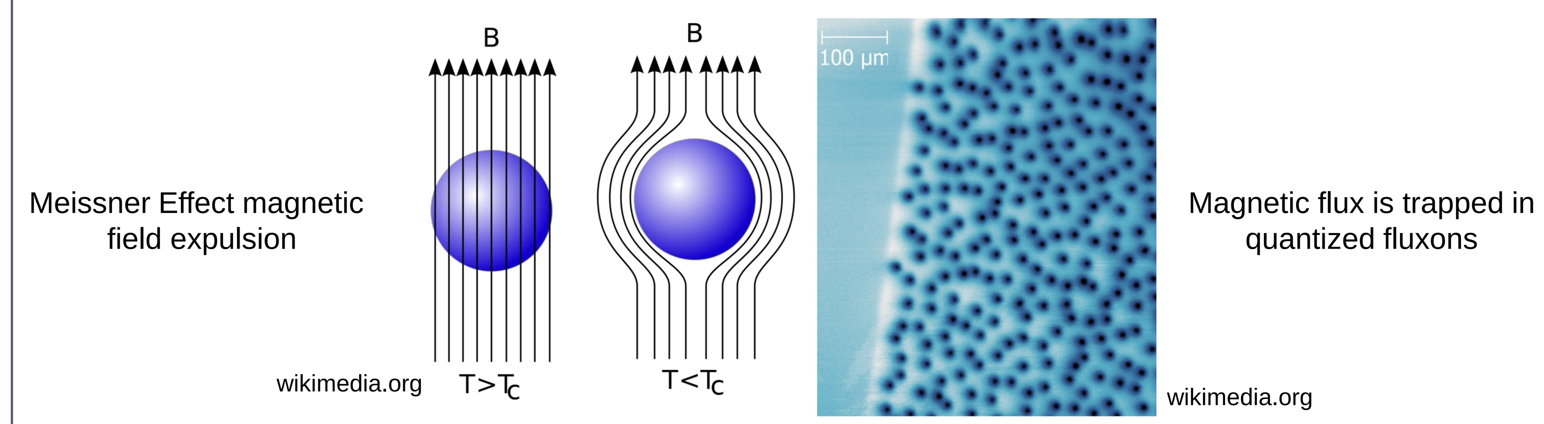


- The device under test was cooled below its critical temperature, T_c, in a liquid nitrogen cryostat.
- Python programming was used to control the spectrum analyzer and digital multimeter for automated data collection.

Instruments & Equipment:

1) Liquid nitrogen cryostat
2) DC field solenoid
3) Temperature controller
4) Signal generators
5) Spectrum analyzer
6) Bias power supply
7) Solenoid power supply
8) Digital multimeter

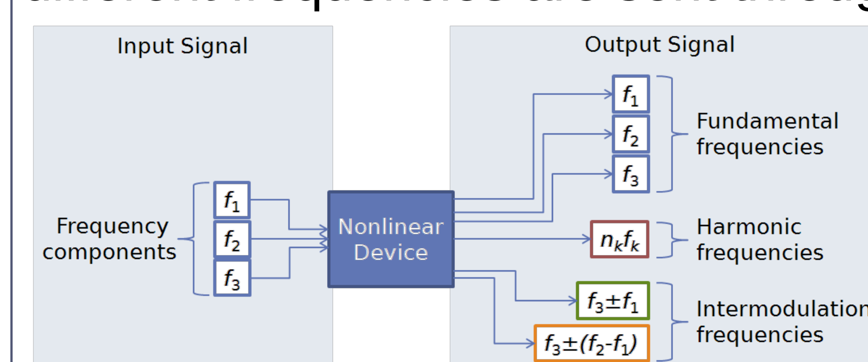
Flux Pinning



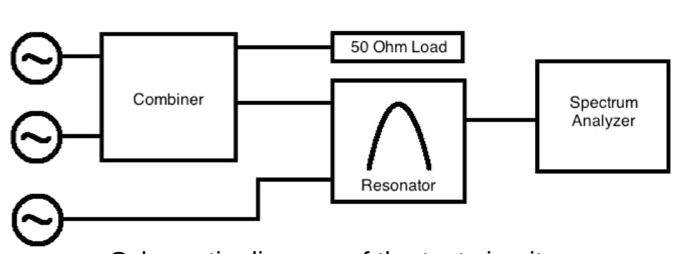
Superconducting materials expel magnetic field when cooled below T_C. In type-II superconductors, magnetic flux lines are pinned in quantized fluxons. The fluxons create vortex currents that distort electric signals.

Intermodulation

Intermodulation is generated when multiple input signals of different frequencies are sent through a nonlinear device.



The IM signals measured in this experiment are generated at $f_3 + f_1$ and $f_3 - (f_2 - f_1)$.



Schematic diagram of the test circuit.

IM can be measured in these superconducting devices because of their nonlinear surface impedance:

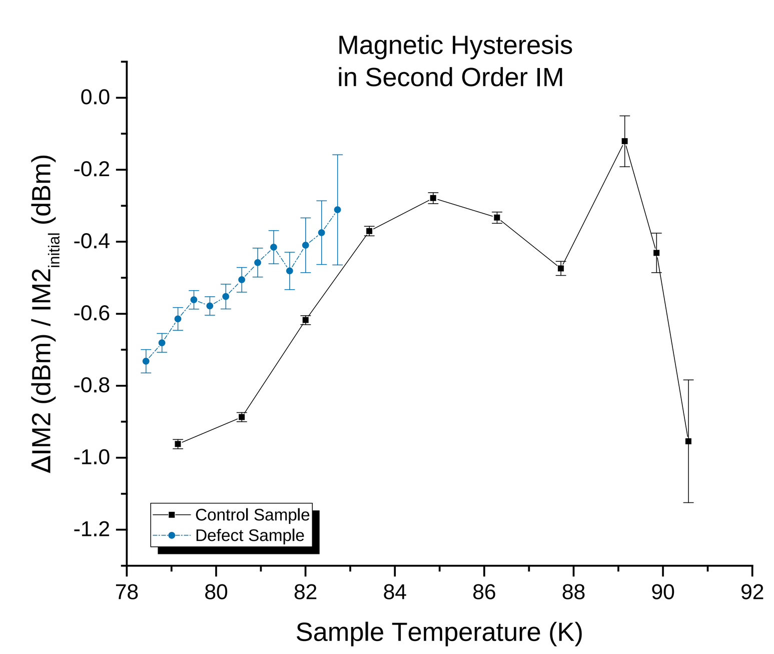
$$V = I * Z(I)$$

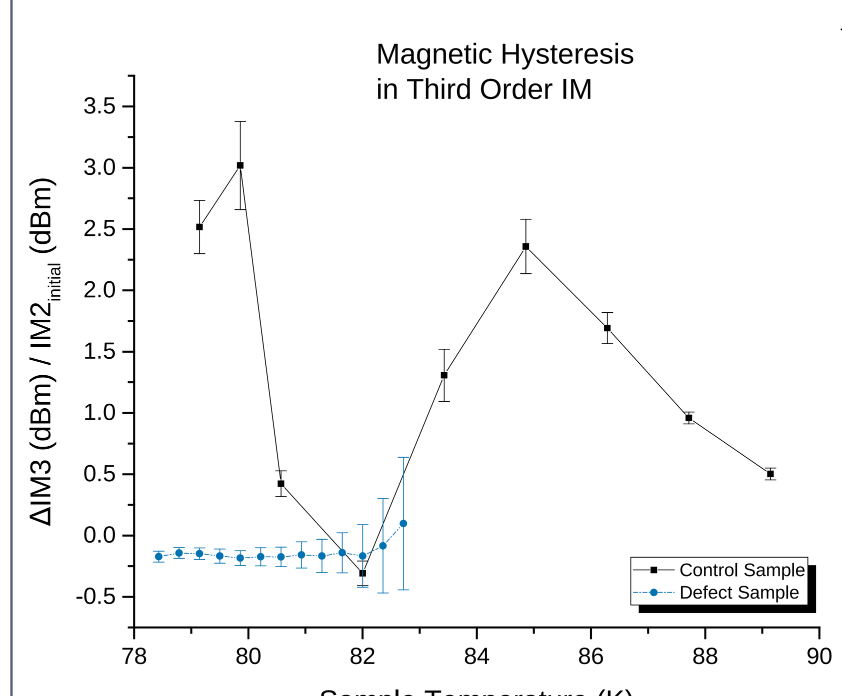
Changes to the level of IM produced indicate changes in the nonlinearity of the sample.

Results: Magnetic Hysteresis

Magnetic hysteresis of second and third order IM is affected by the introduction of defects.

The irradiated sample and control sample exhibit similar temperature dependence in magnetic hysteresis of second order IM. Compared to the control sample, magnetic hysteresis in the defect sample is suppressed by a factor of approximately 0.2.





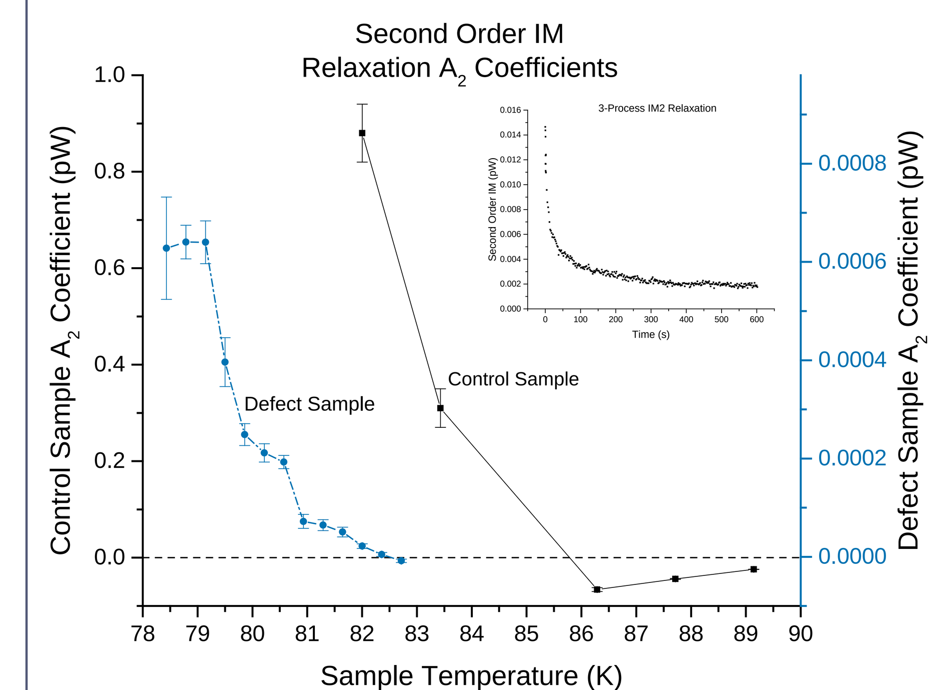
The irradiated sample exhibits insignificant temperature dependence in magnetic hysteresis of third order IM. This contrasts what appears to be significant and complex amounts of IM3 hysteresis in the control sample. IM3 in the defect sample decreases by a constant factor of approximately 0.5, while the control sample IM3 increases by varying amounts.

Results: Relaxation

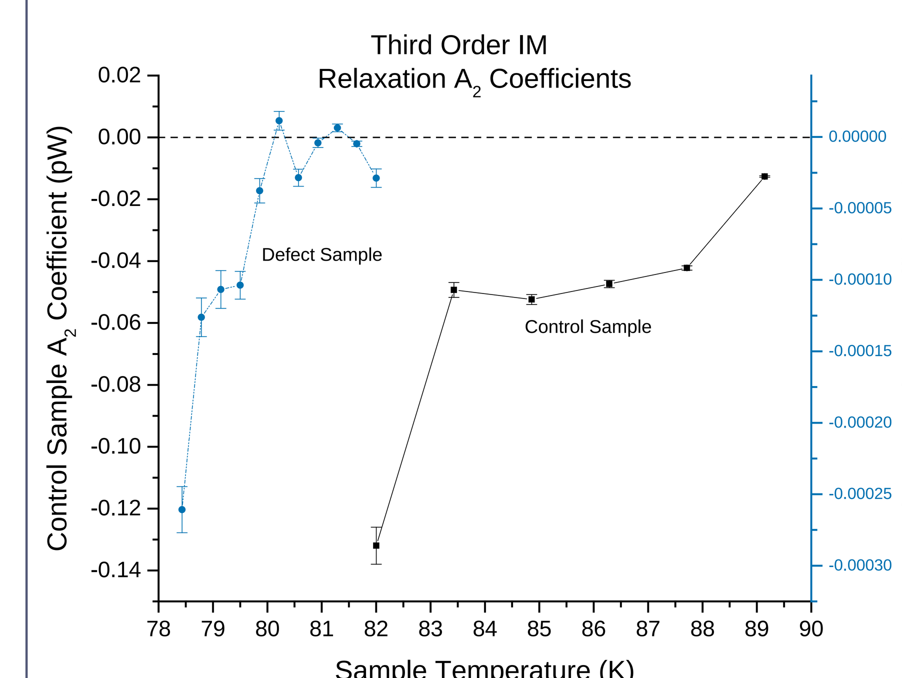
Second order IM in the control sample exhibits several relaxation processes described by

$$y(t) = B + A_0 e^{-\frac{t}{t_0}} + A_1 e^{-\frac{t}{t_1}} + A_2 \log_{10}(t)$$

The second exponential term is due to remanent demagnetization in the sample, and the logarithmic term comes from magnetic relaxation as described by Bean and Livingston. The mechanism behind the first exponential term is still under investigation.



The irradiated sample has highly suppressed IM that causes its A_2 parameter to be 3 orders of magnitude smaller than the control sample. Both samples exhibit decreasing values in A_2 as the sample temperature approaches T_c until A_2 changes signs, where the relaxation process becomes concave down. A_2 in the defect sample changes signs at roughly 3 Kelvin lower than the control sample. The inlaid graph demonstrates a typical control sample IM2 measurement including all three relaxation processes.



A_2 in third order IM exhibits similar temperature dependence to second order IM but instead approaches 0 from negative values. This gives the time evolution of IM3 a concave-down appearance except near T_c. The defect sample IM3 appears to change concavity multiple times as at approaches T_c, while the control sample is always concave down.

Improved measurements are needed to determine the behavior of time constants t_0 and t_1.

Conclusions

- Defects suppress the strength of second and third order IM and lower the T_c.
- Adding defects removes significant temperature dependence in the magnetic hysteresis of third order IM.
- The irradiated sample exhibits no exponential processes in its relaxation. The enhanced pinning in the defects cause logarithmic Bean-Livingston relaxation to dominate.
- The defect sample Bean-Livingston process changes concavity at a lower temperature than the control sample for both second and third order IM.

Acknowledgements

Rick Huizen
Sean Hamilton
Dave Daugherty
Hope College
The National Science Foundation

Hope COLLEGE

This material is based upon work supported by the National Science Foundation under Grant Number DMR-1505617.