# Electrical Properties of 20/80 PZT and 3/20/80 PNZT from 5 K to Room Temperature

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&

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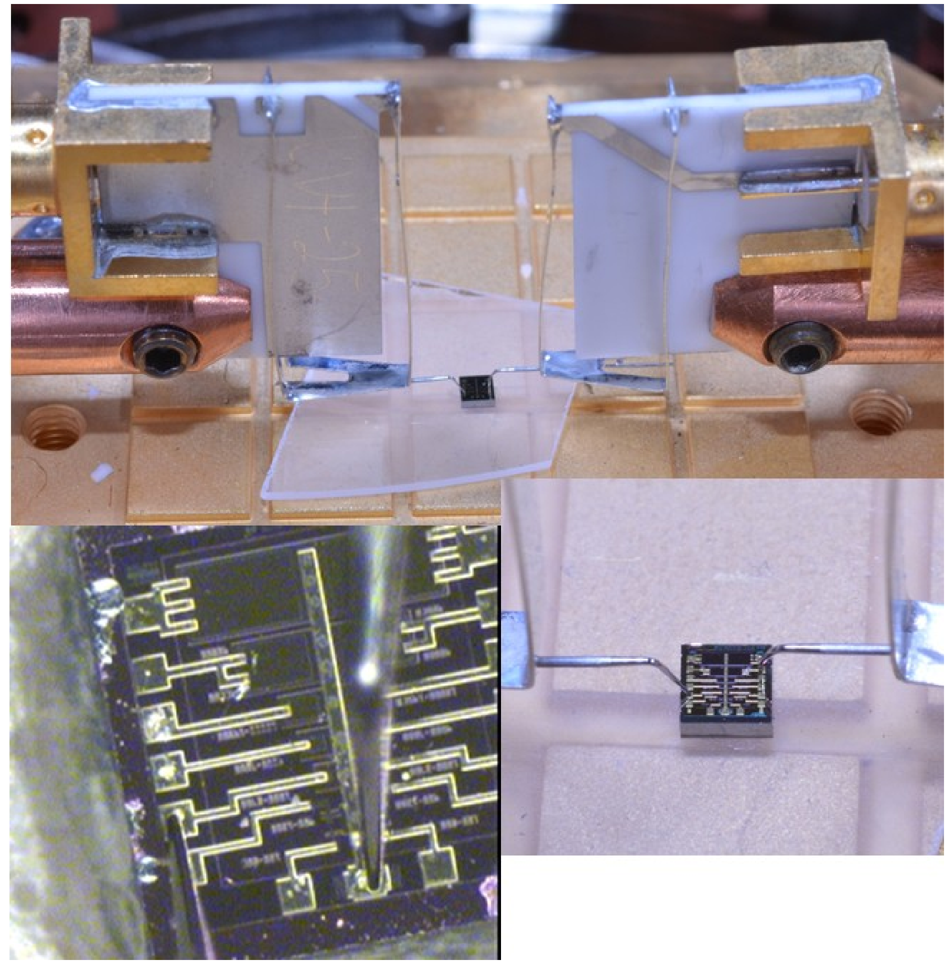
# Test Equipment

- Lake Shore Cryotronics and Radiant Technologies together measured the electrical properties of **20/80 PZT** and **3/20/80 PNbZT** thin ferroelectric film capacitors from **5 K** up to **300 K**.

- The Vision data acquisition program executed automated tests of *single samples* over a wide temperature range, commanding temperature changes using GPIB.

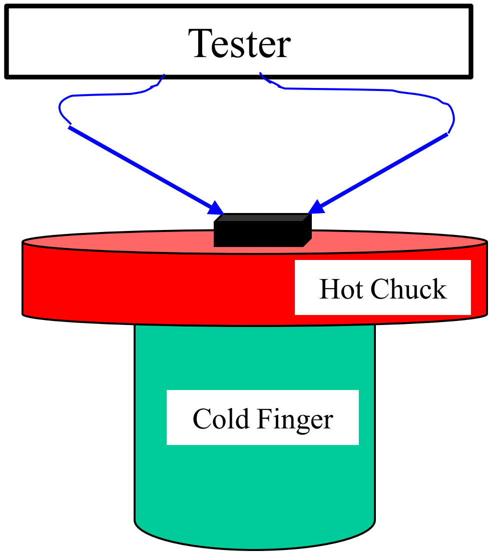
- Thermally-compensated electrical probe tips in the Lake Shore cryogenic chamber maintained electrical contact with the sample over the large temperature changes.

# Lake Shore Cryogenic Chamber



# Lake Shore Cryogenic Chamber

- The Lake Shore Cryotronics CRX-4K chamber has a hot chuck placed above a cold finger.
- The cold finger first dropped to 5.0 K while the hot chuck maintained the sample at room temperature.
- The hot chuck was then set to the first temperature of the test profile and testing began.
- For temperature changes, the controller used a ramp rate of 3°K per minute and then soaked the sample at the new temperature for 10 minutes before starting tests.

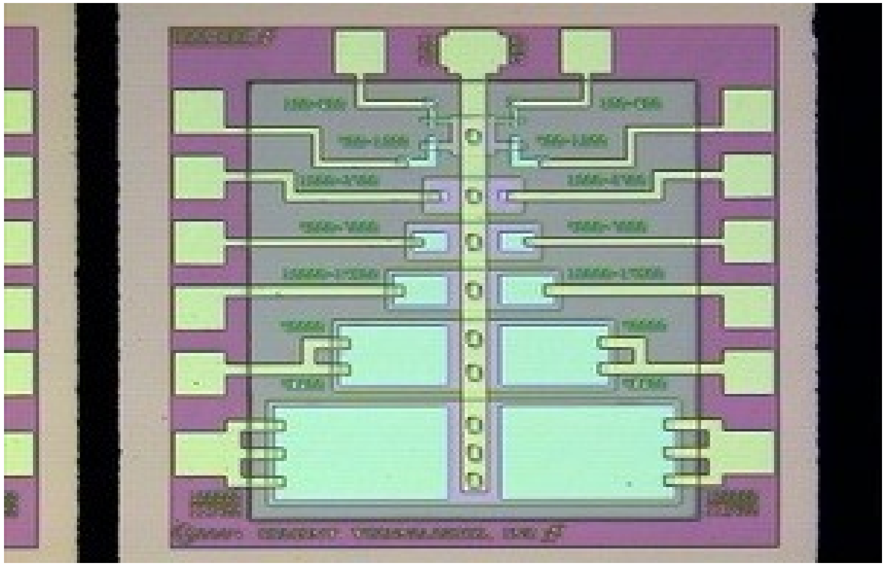


# Sample Descriptions

- Capacitor structure:
  - Platinum top and bottom electrodes
  - Glass passivation above the capacitor
  - Chrome/Gold probe pads and traces

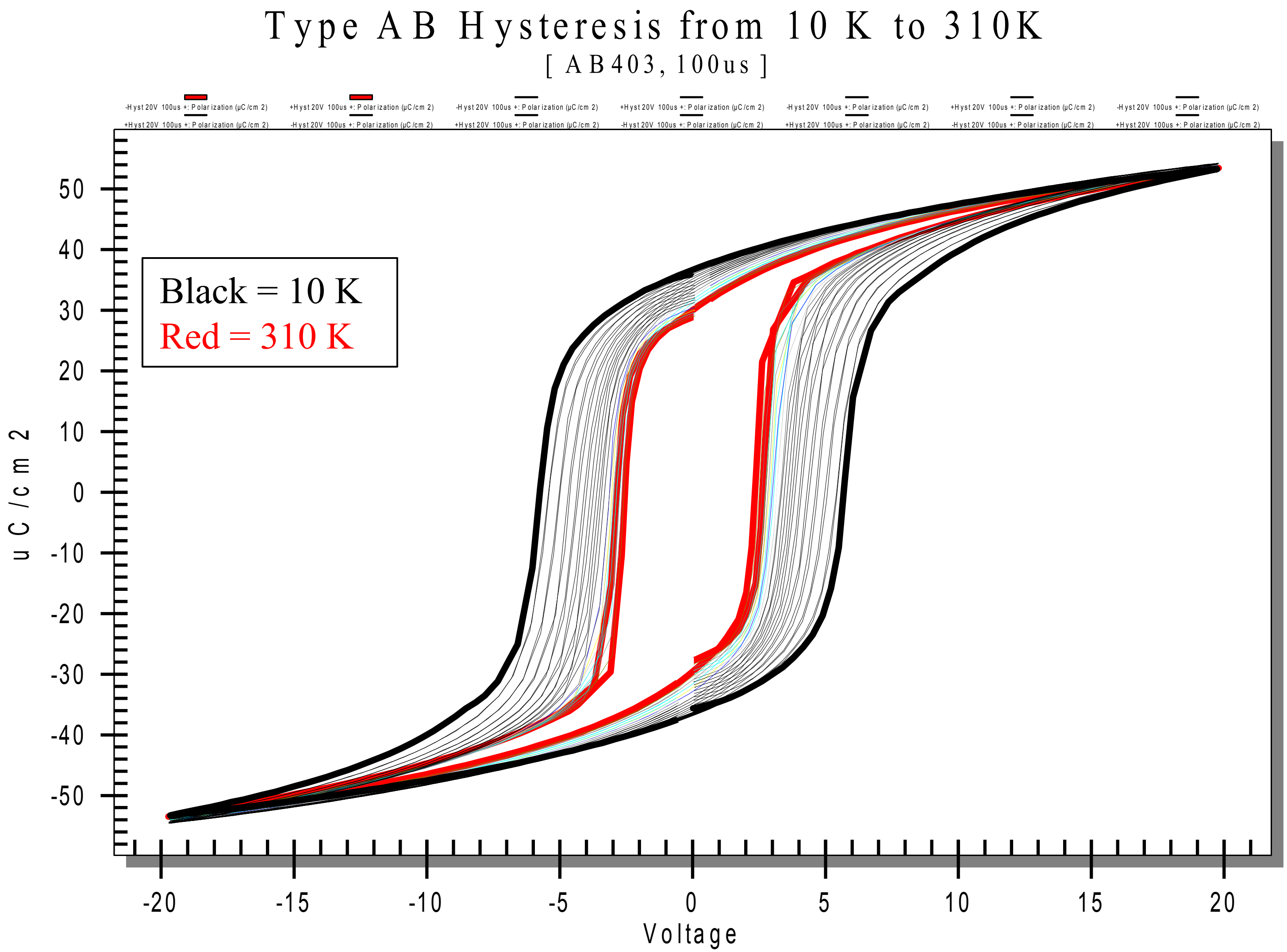
- Tested areas were 100µm$^2$ & 40,000µm$^2$.

- Thicknesses:
  - 20/80 PZT = 2,600Å
  - 3/20/80 PNbZT = 1,500Å



# Hysteresis vs Temperature

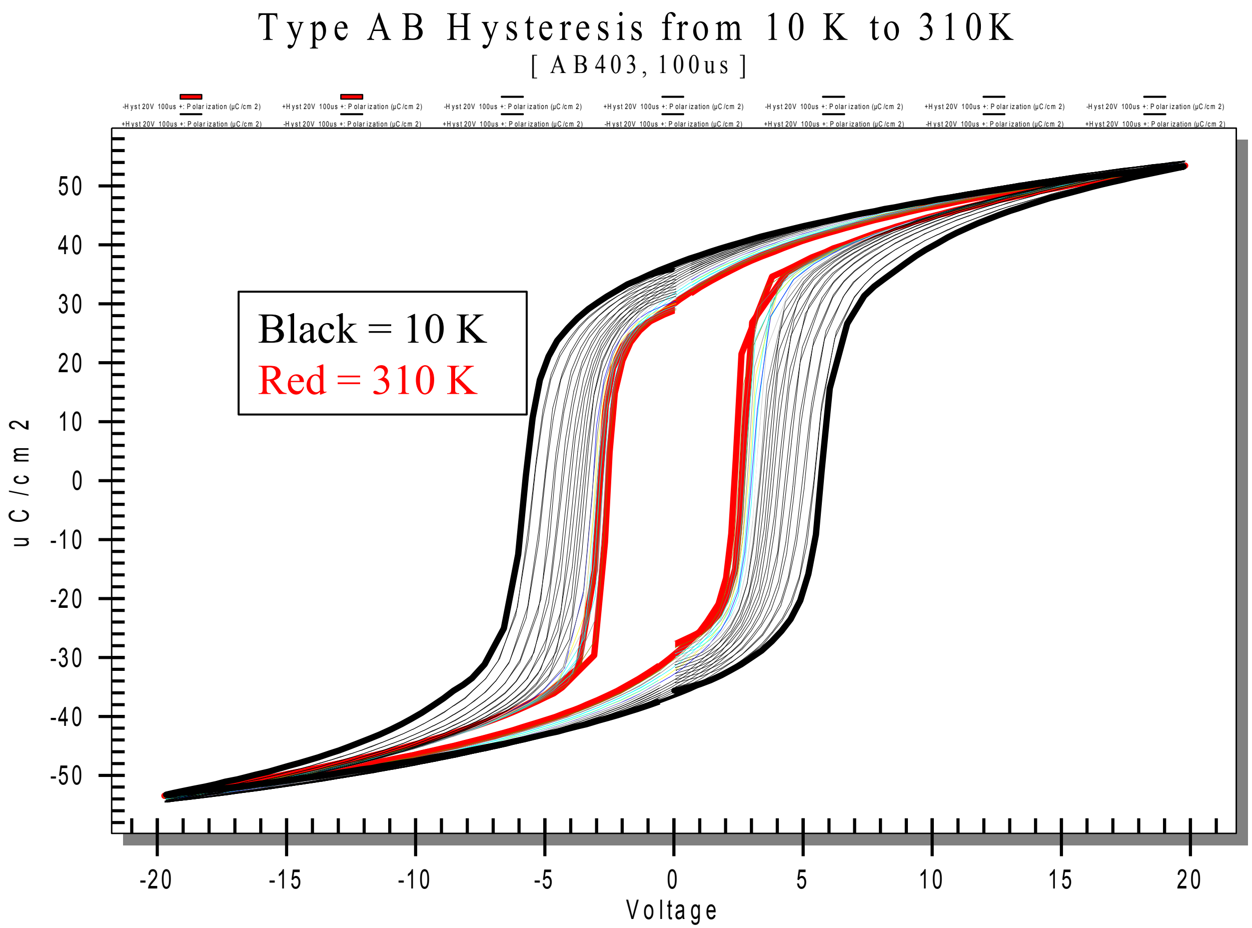
## 40,000 μm$^2$ 20/80 PZT




Radiant Technologies, Inc.

# Hysteresis vs Temperature

## 40,000 µm$^2$ 20/80 PZT

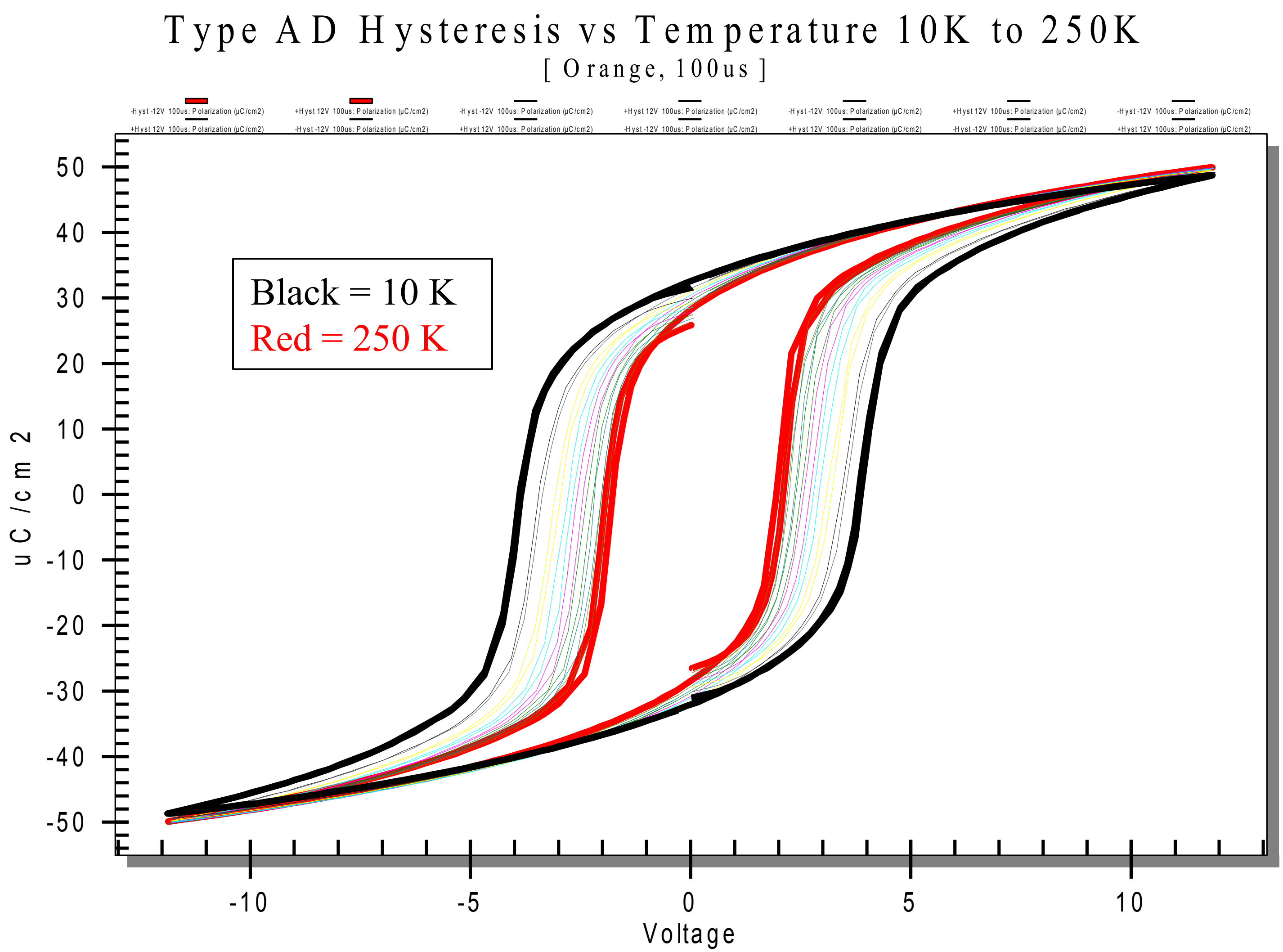



*20 volts was necessary at 10 K for saturation but the 100 µs test period prevented breakdown of the at 20 volts at room temperature.*

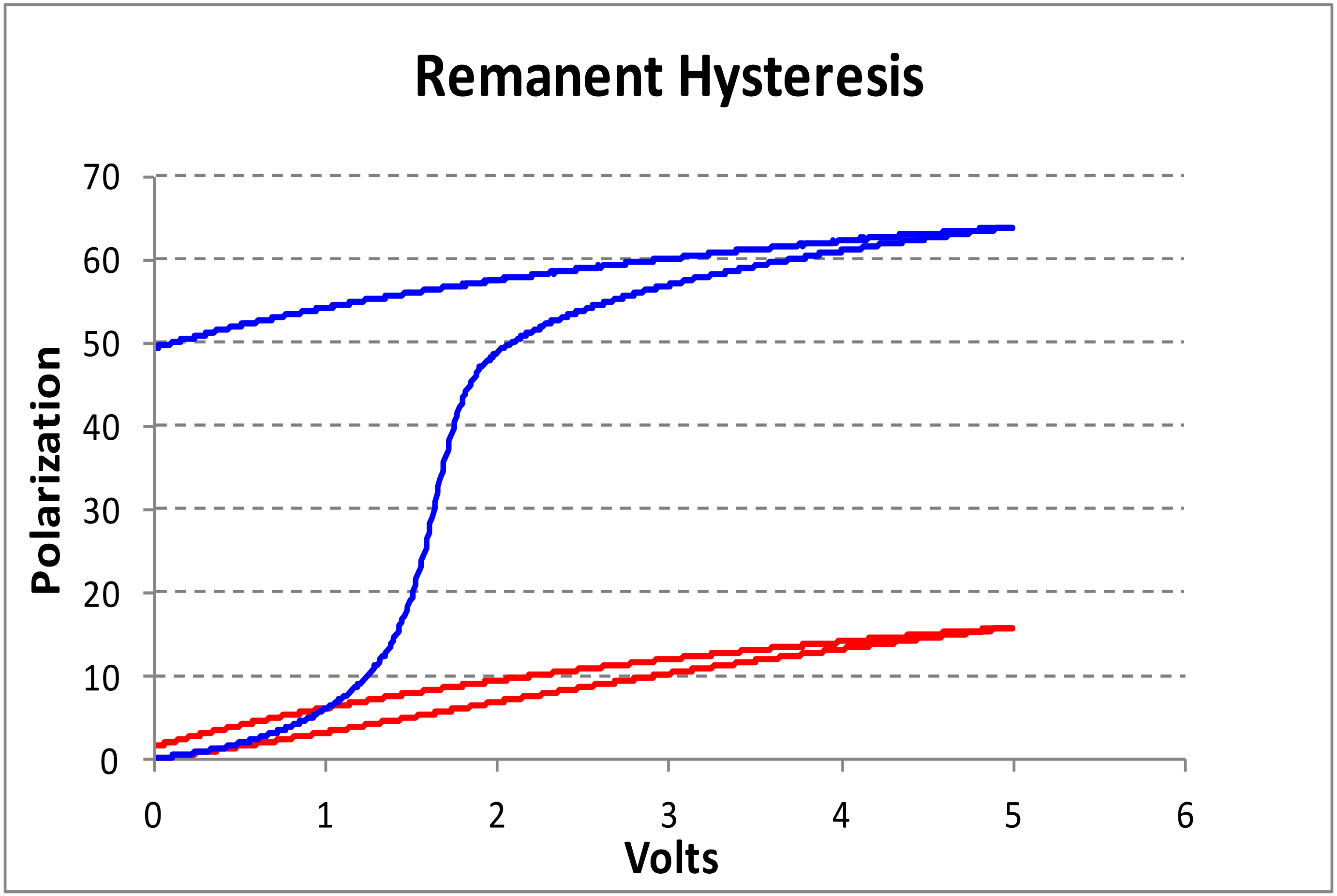
*The test voltage vs temperature vs frequency envelope must be evaluated before starting long automated tests.*

# Hysteresis vs Temperature

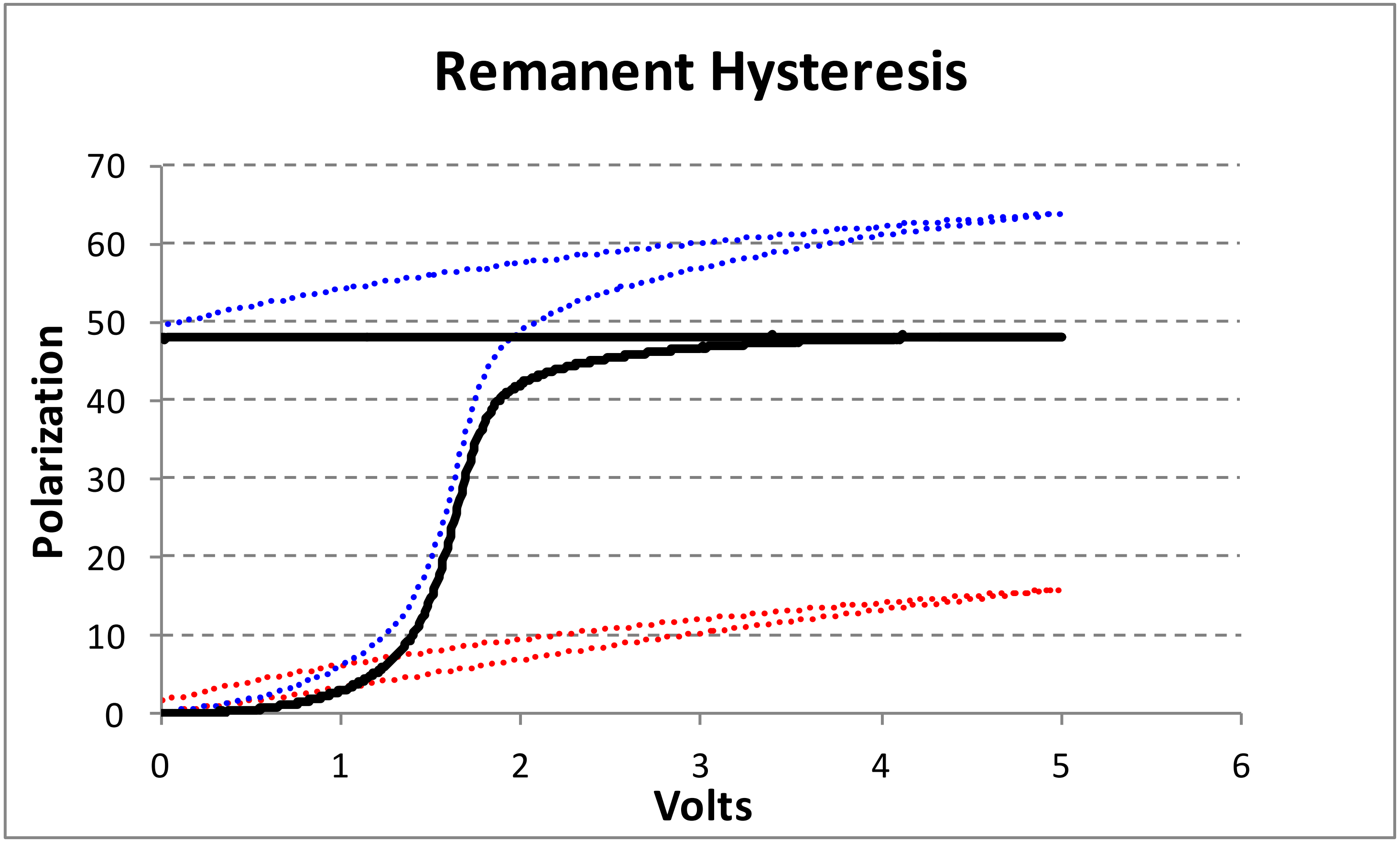
## 40,000 µm² 3/20/80 PNZT



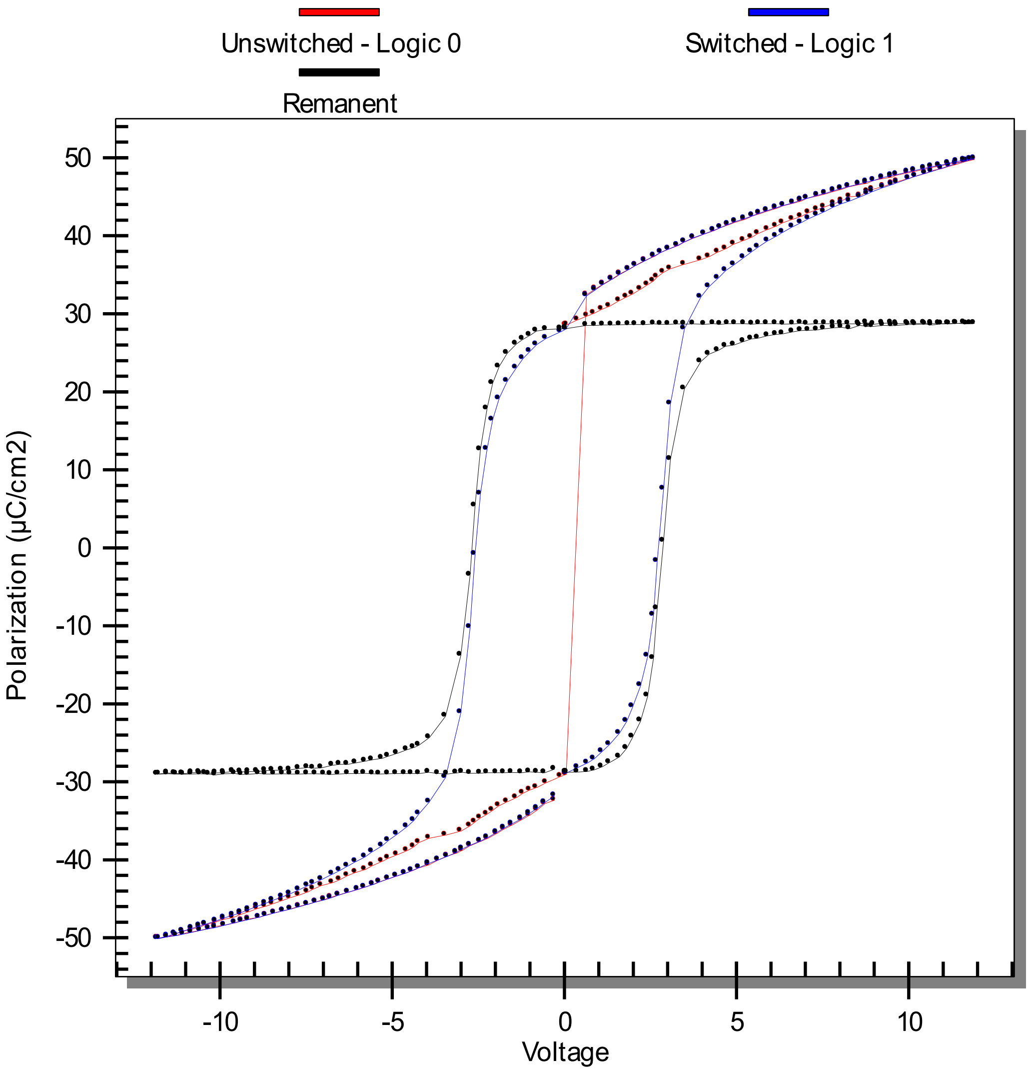
# Remanent Hysteresis



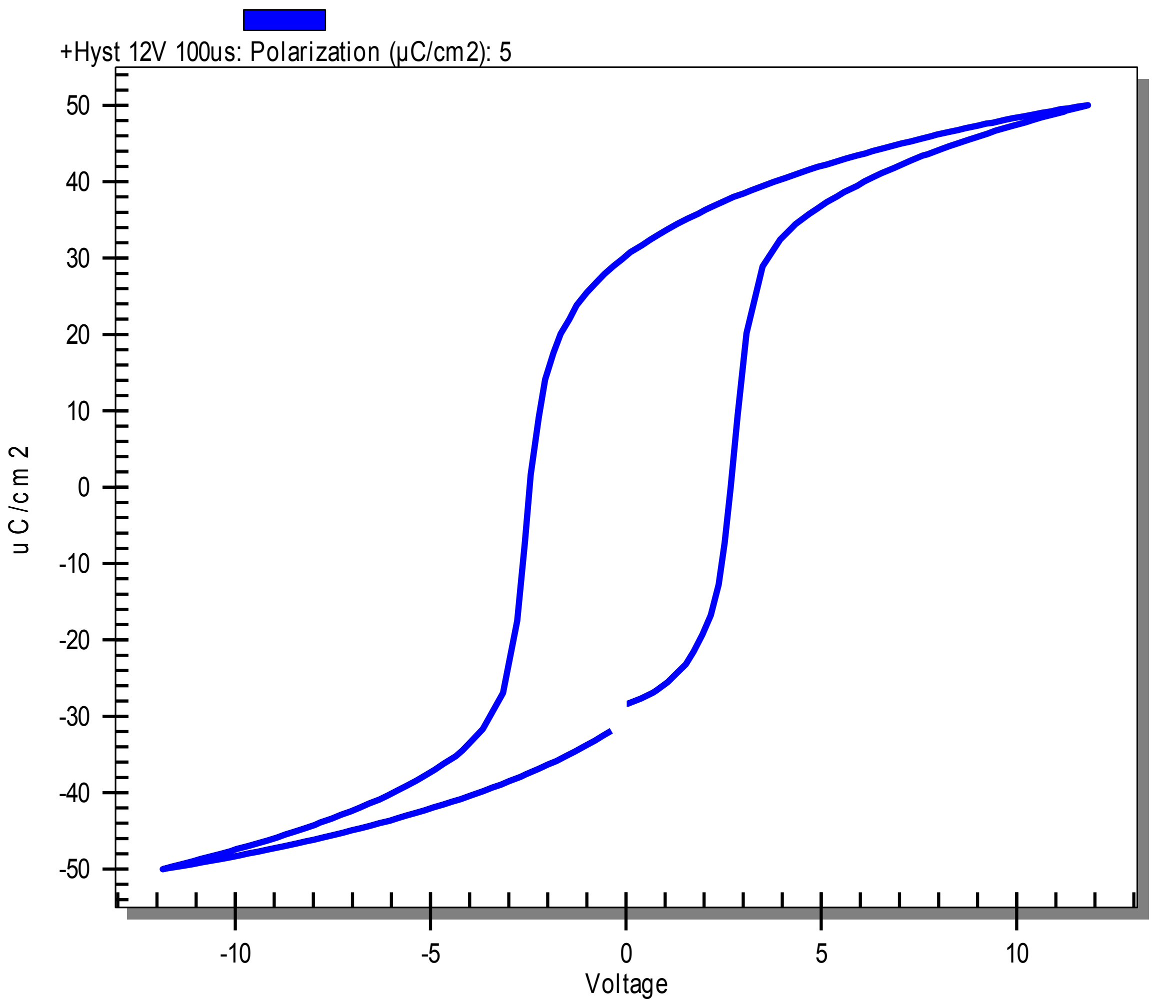
# Remanent Hysteresis



# Remanent Hysteresis Task



# Remanent Hysteresis vs Full Hysteresis



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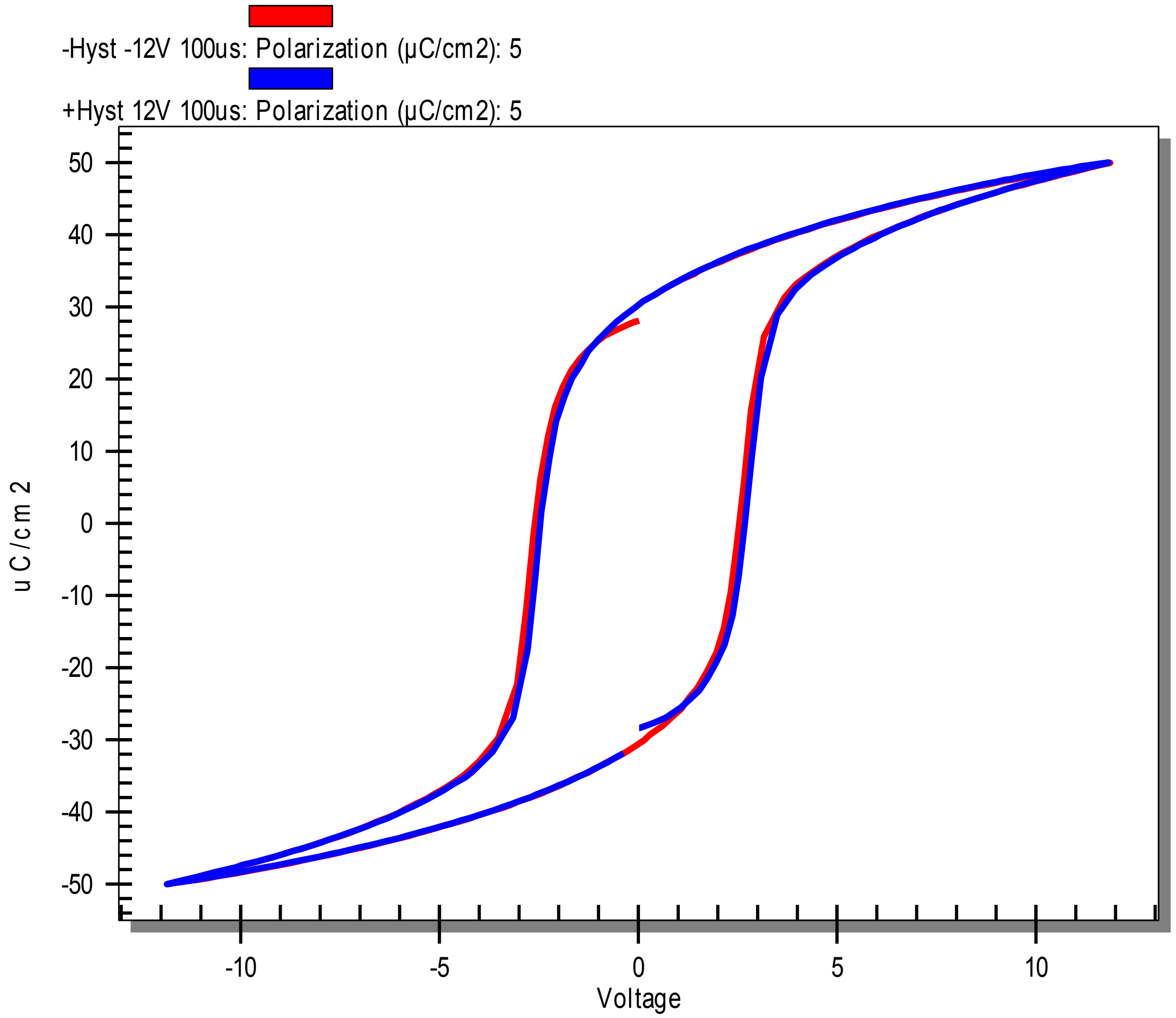
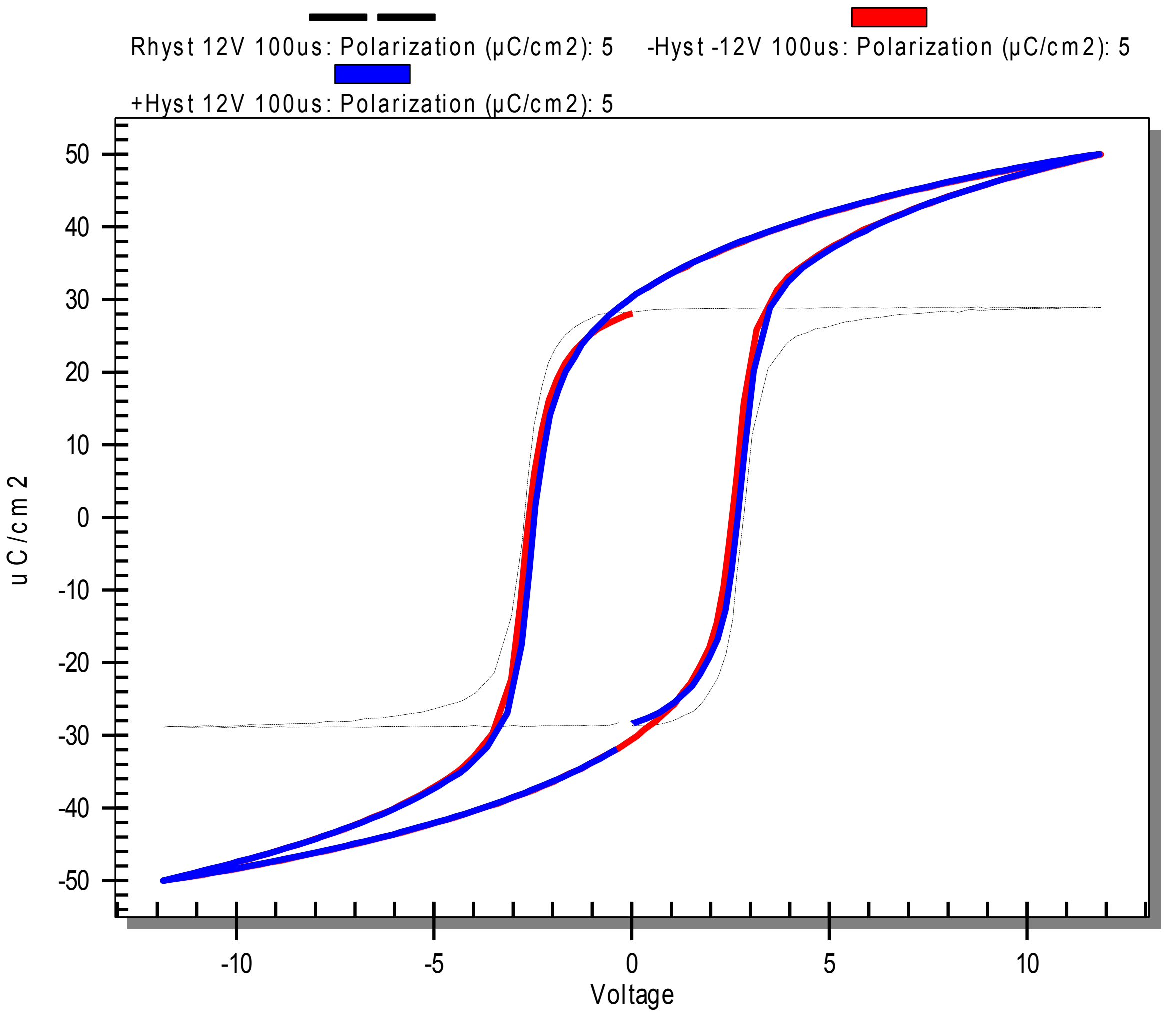


# Remanent Hysteresis vs Full Hysteresis



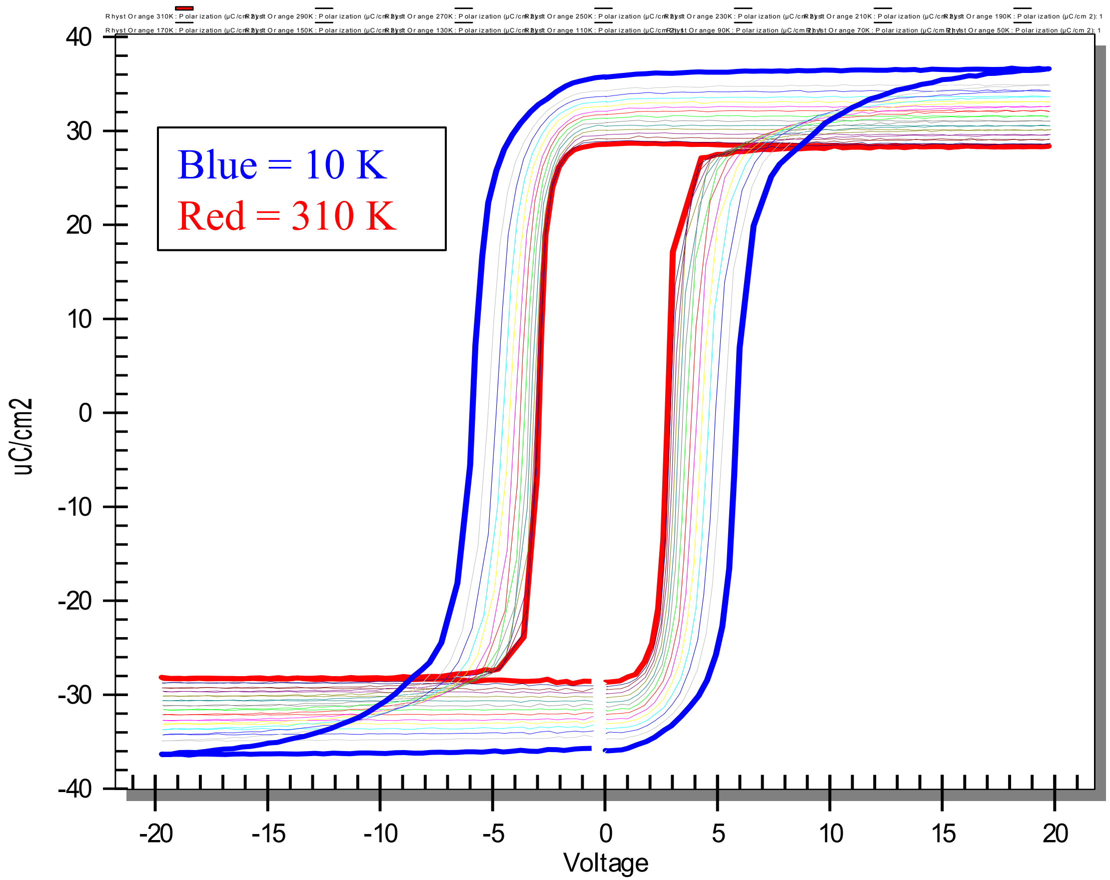
# Remanent Hysteresis vs Temperature

## 40,000 µm$^2$ 20/80 PZT

- 20 volts with 100 microsecond period.

Remanent Hysteresis 10k->310K

[ AB403, 100us ]



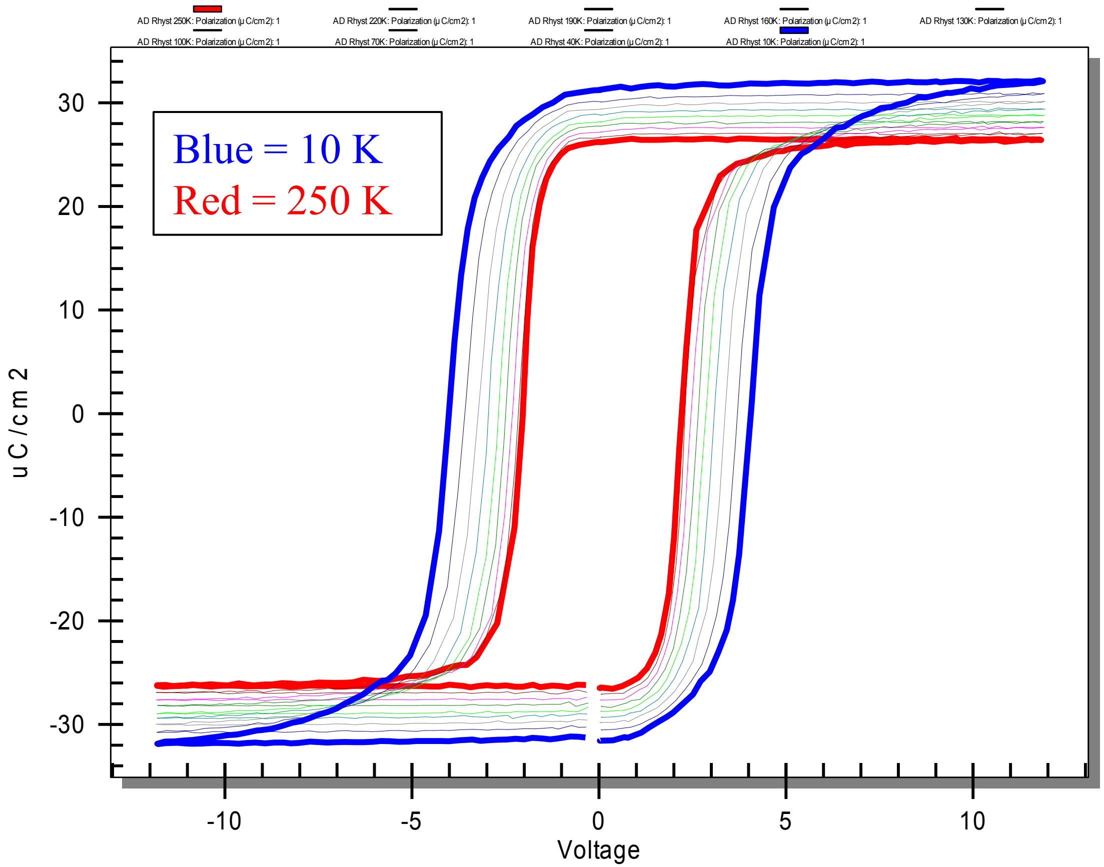
# Remanent Hysteresis vs Temperature

## 40,000 μm$^2$ 3/20/80 PNZT

- 12 volts with 100 microsecond period.

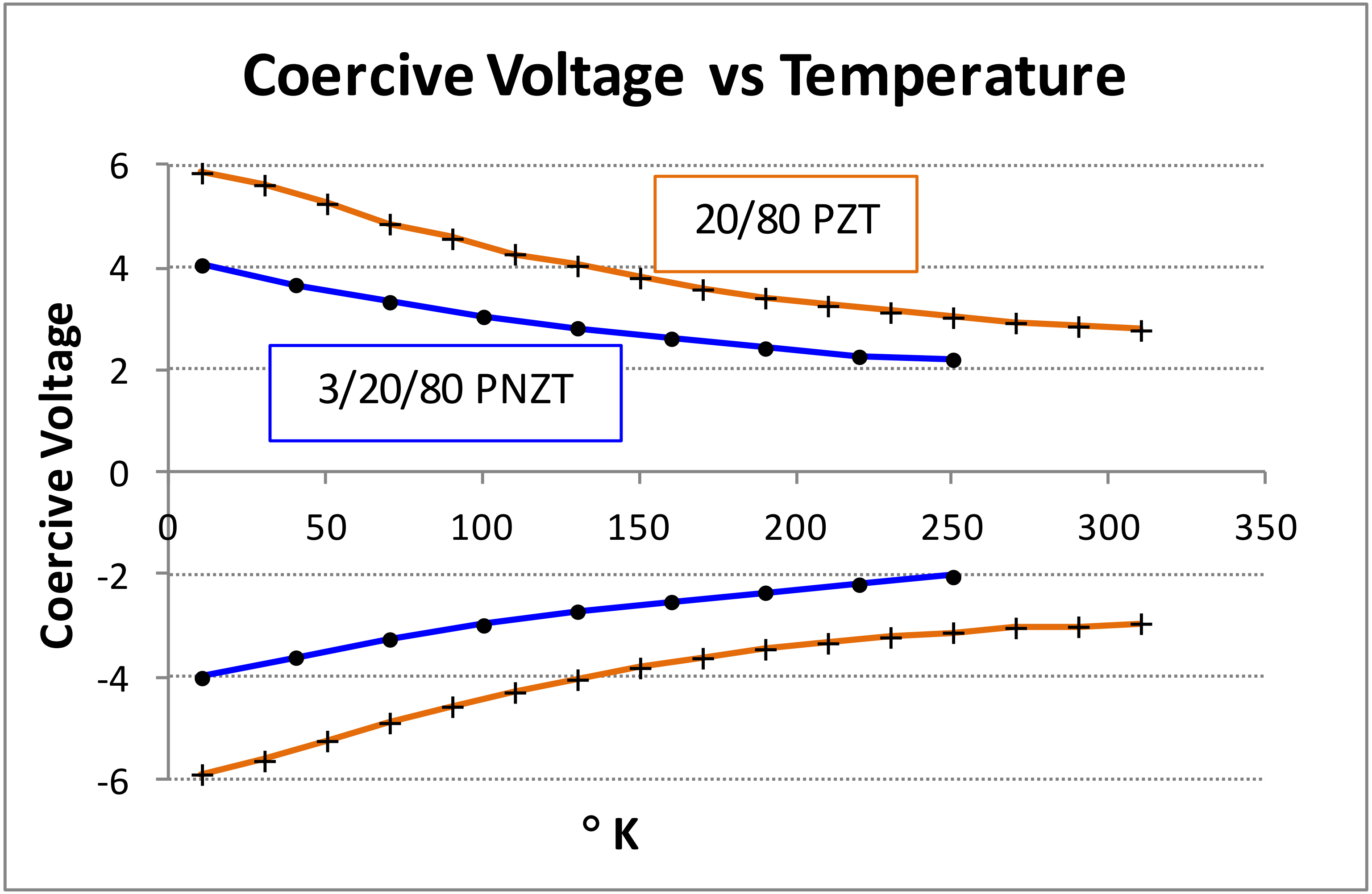
Type AD Remanent Hysteresis 10k->250K

[ AD403, 100us ]



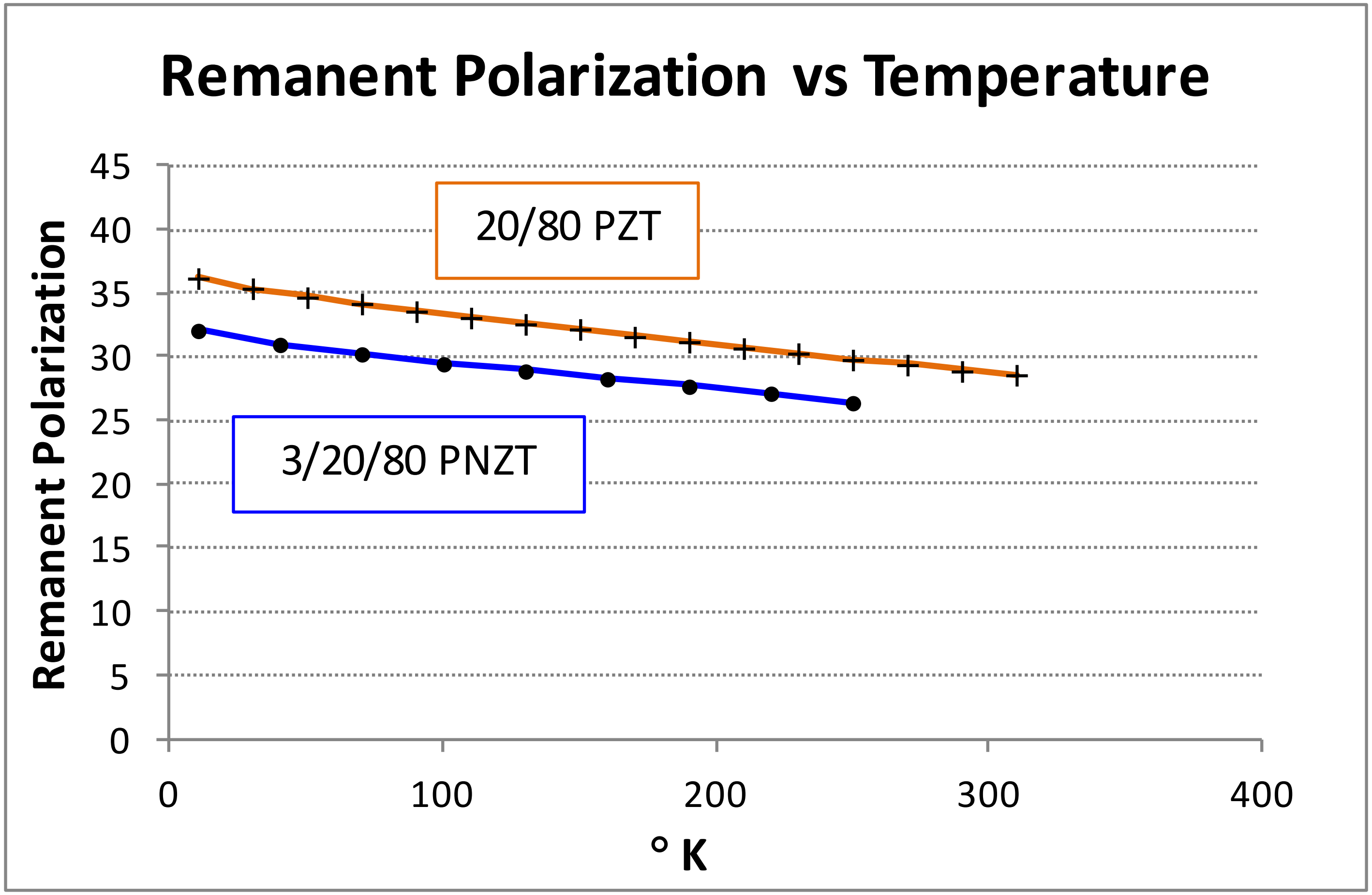
# Coercive Voltage vs Temperature

## 40,000 μm² 3/20/80 PNZT vs 20/80 PNZT

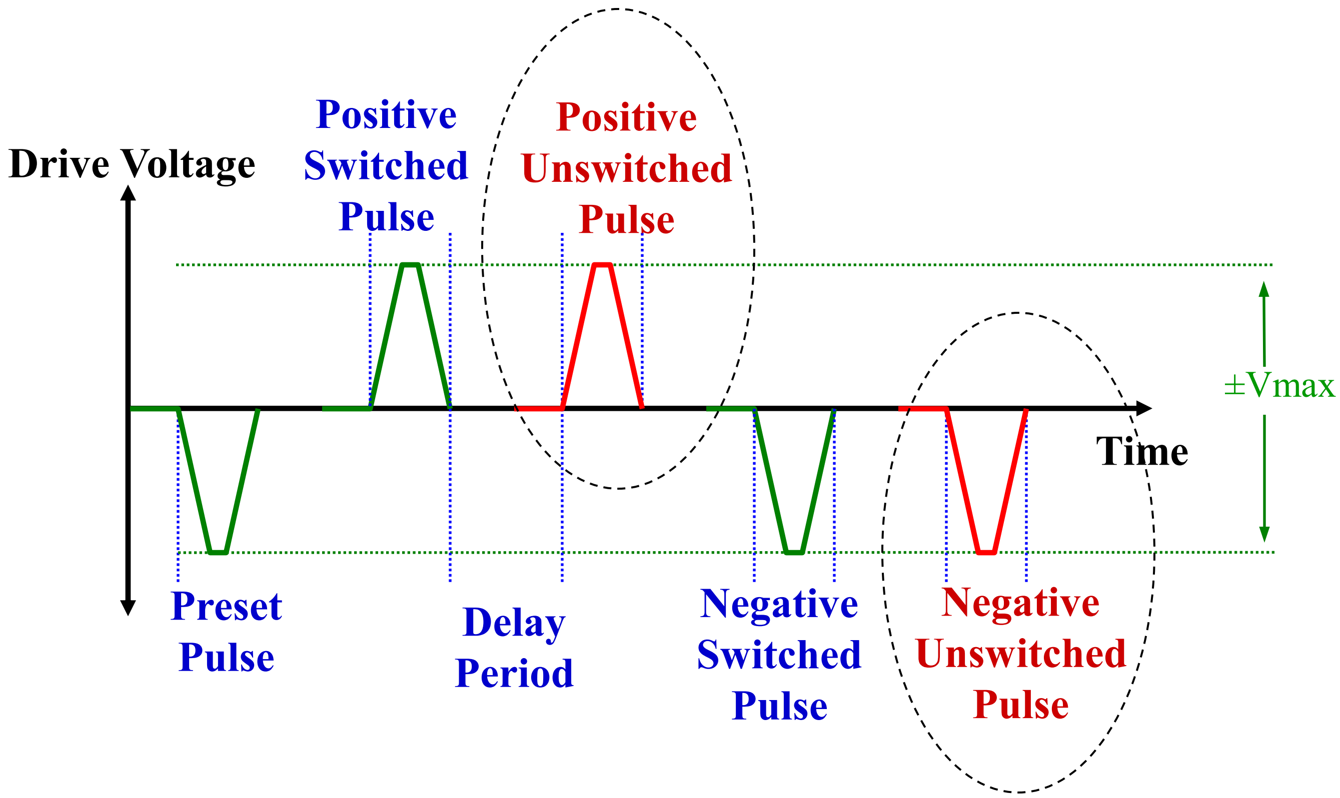


# Remanent Polarization vs Temperature

## 40,000 μm$^2$ 3/20/80 PNZT vs 20/80 PNZT



# PUND


Drive Voltage
Positive Switched Pulse
Positive Unswitched Pulse
±Vmax
Time
Preset Pulse
Delay Period
Negative Switched Pulse
Negative Unswitched Pulse

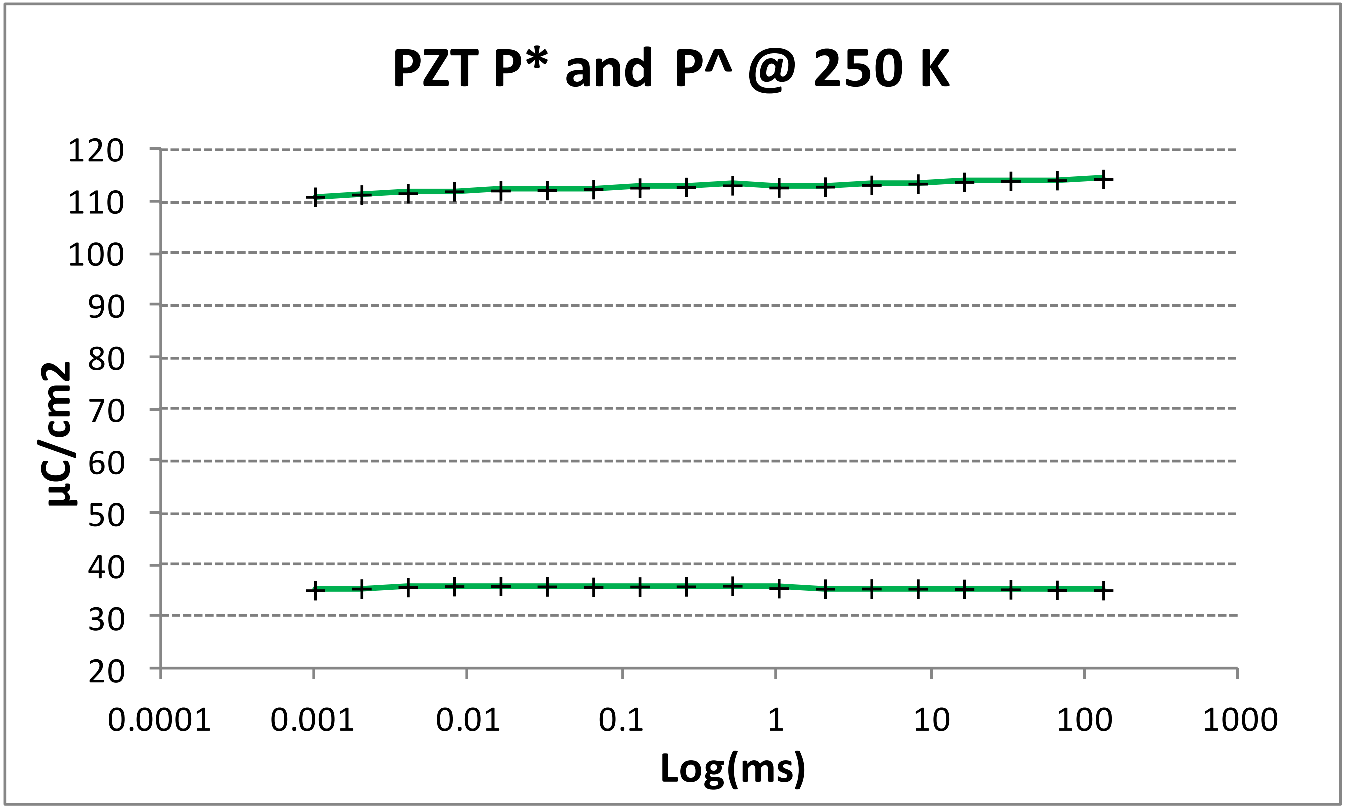
# PUND vs Frequency

## 100 μm² 20/80 PZT

- 9.9 volts from 1μs pulse width to 131ms pulse width.

- Definitions:

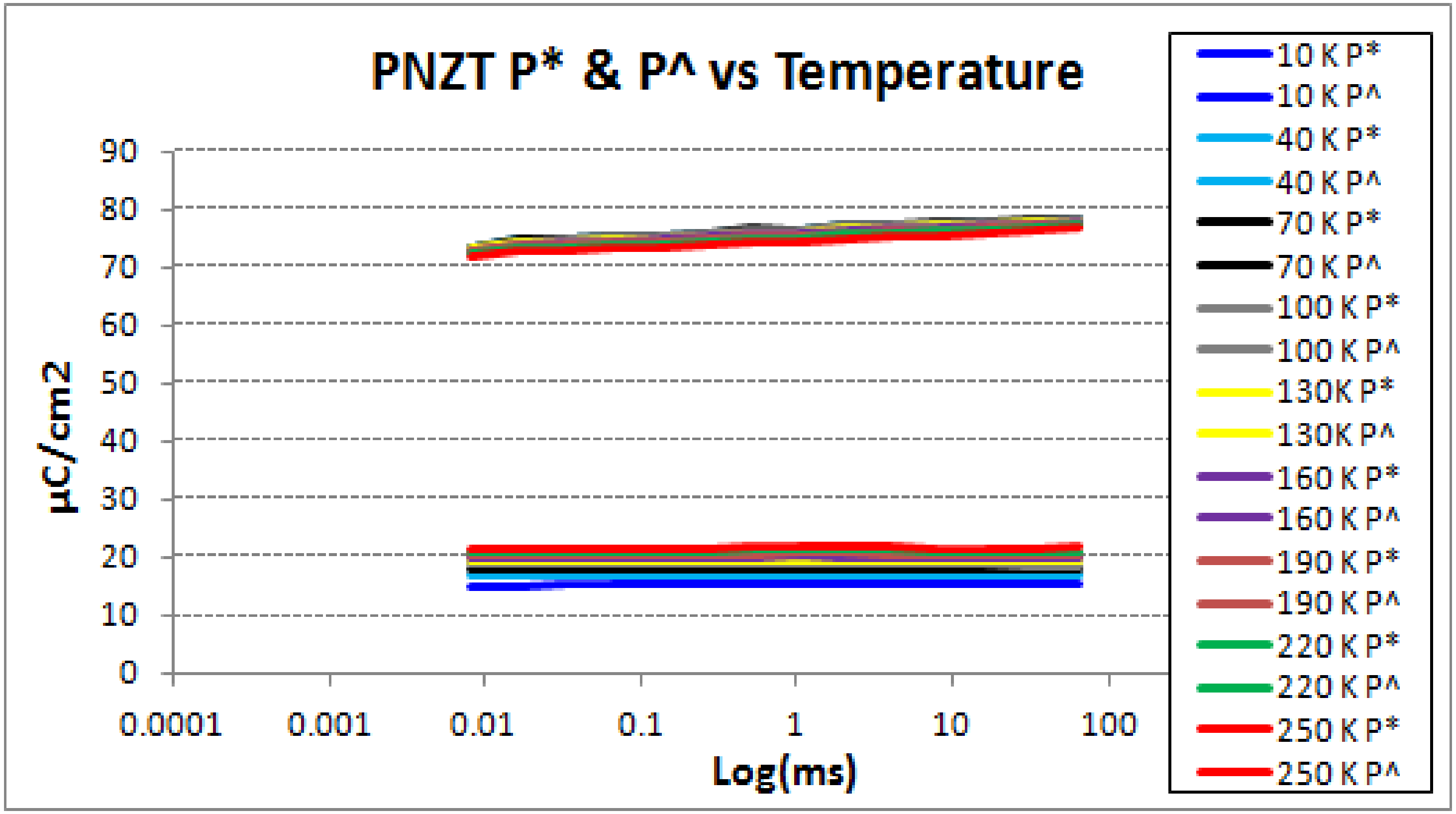
  P* = switching pulse & P^ = non-switching pulse



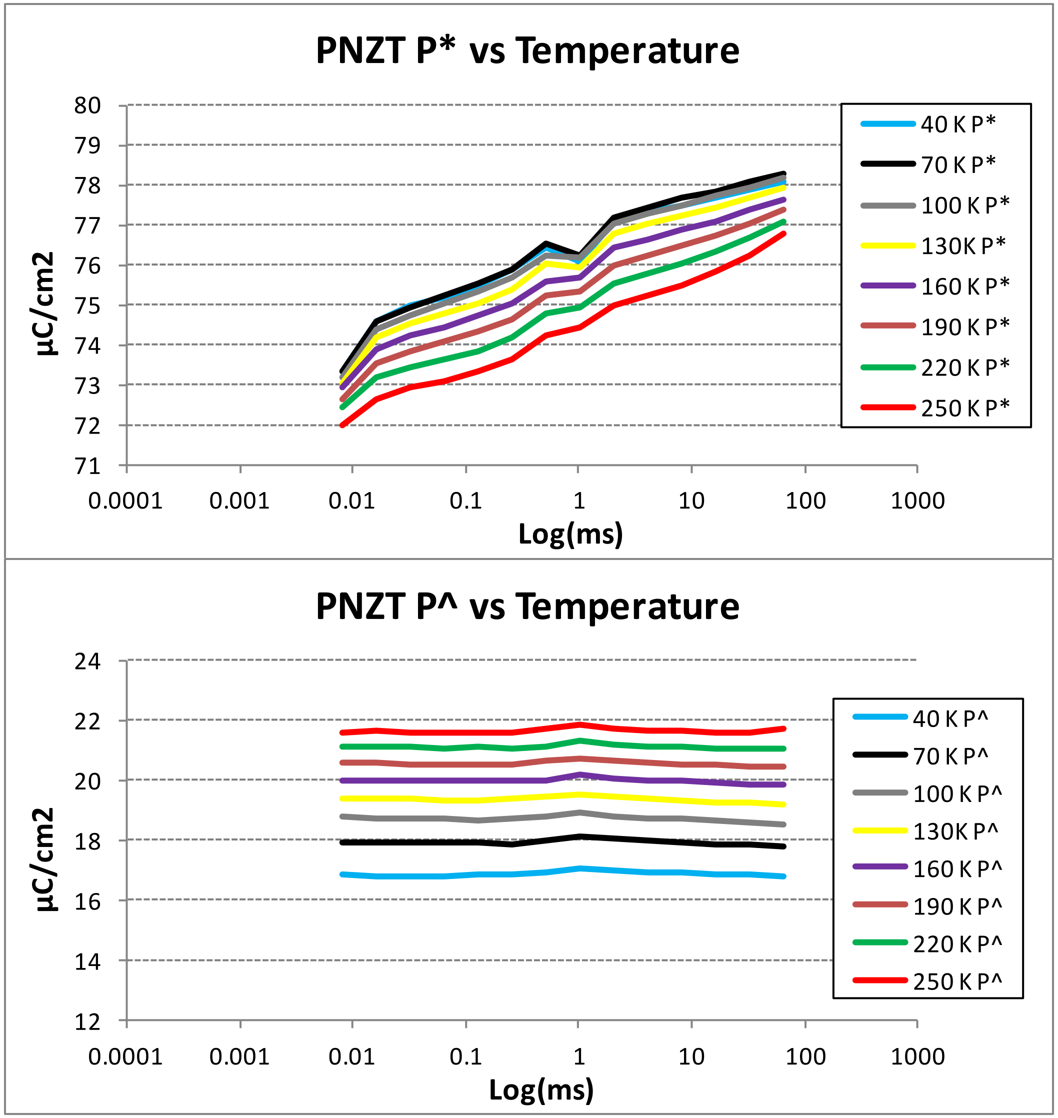
# Speed vs Temperature
## 40,000 $\mu m^2$ 3/20/80 PNZT

- 9.9 volts from 10μs pulse width to 131ms pulse width.
- Definitions:

  P* = switching pulse & P^ = non-switching pulse



# Speed vs Temperature

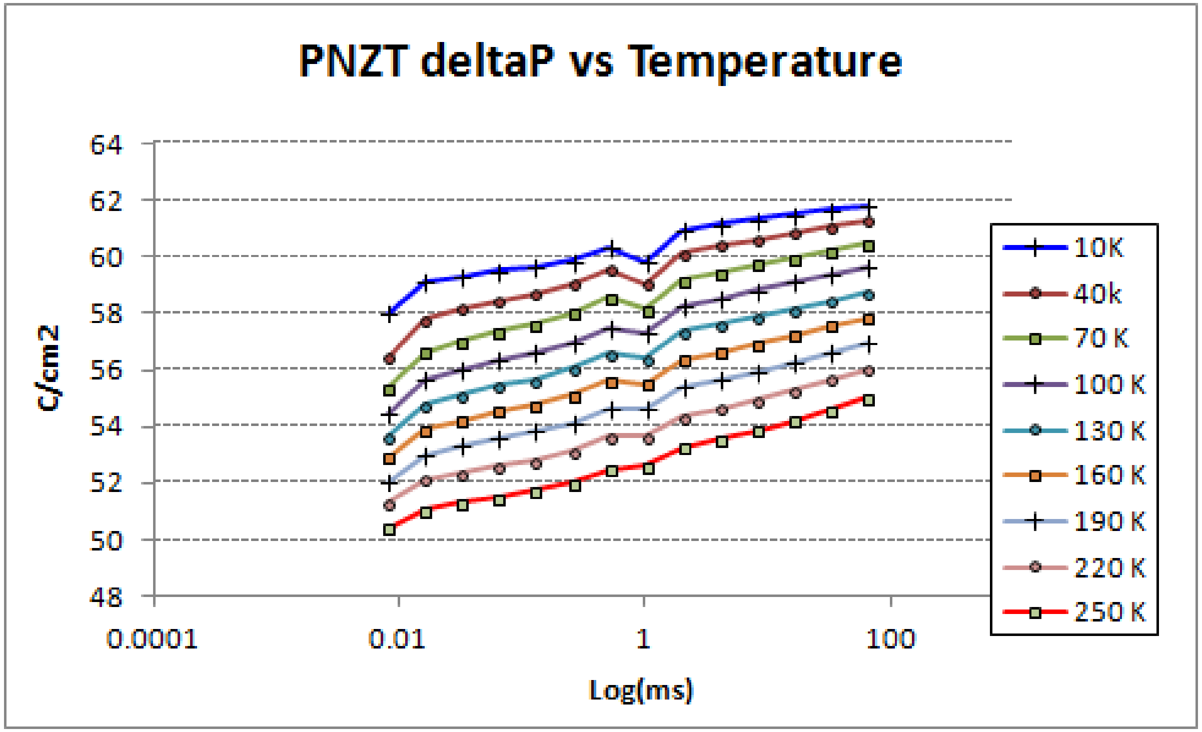



For both 20/80 PZT and 3/20/80 PNZT, when temperature increases the P* decreases while the P^ increases at a greater rate.

# PUND vs Temperature

## 40,000 μm² 3/20/80 PNZT

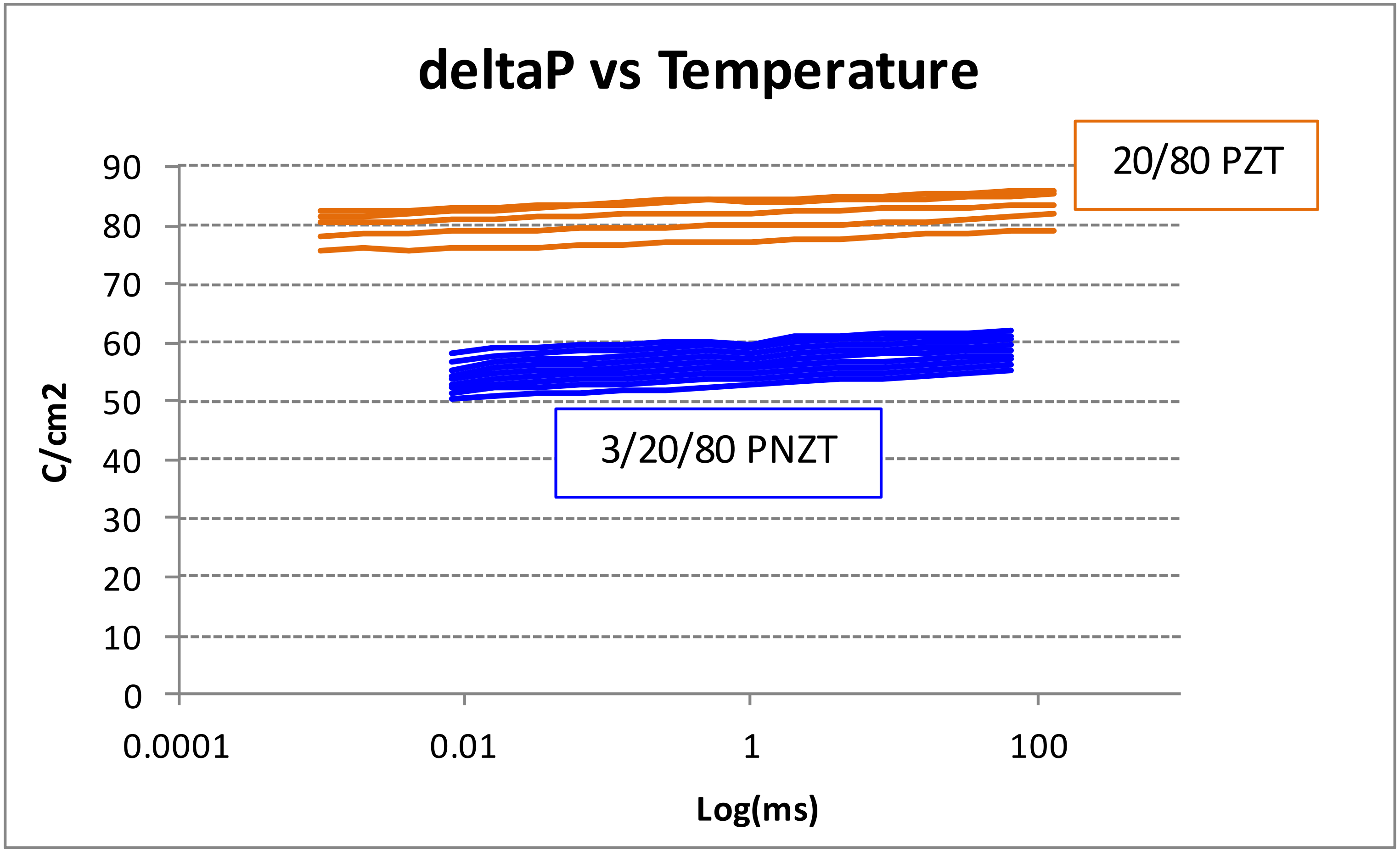
- dP = P* - P^ = 2 x remanent polarization




- The remanent polarization decreases its magnitude with *increasing* temperature.
- The remanent polarization decreases in magnitude with *decreasing* pulse width.
- The switching speed vs pulse width slope remains constant down to 50 K.

# deltaP vs Temperature

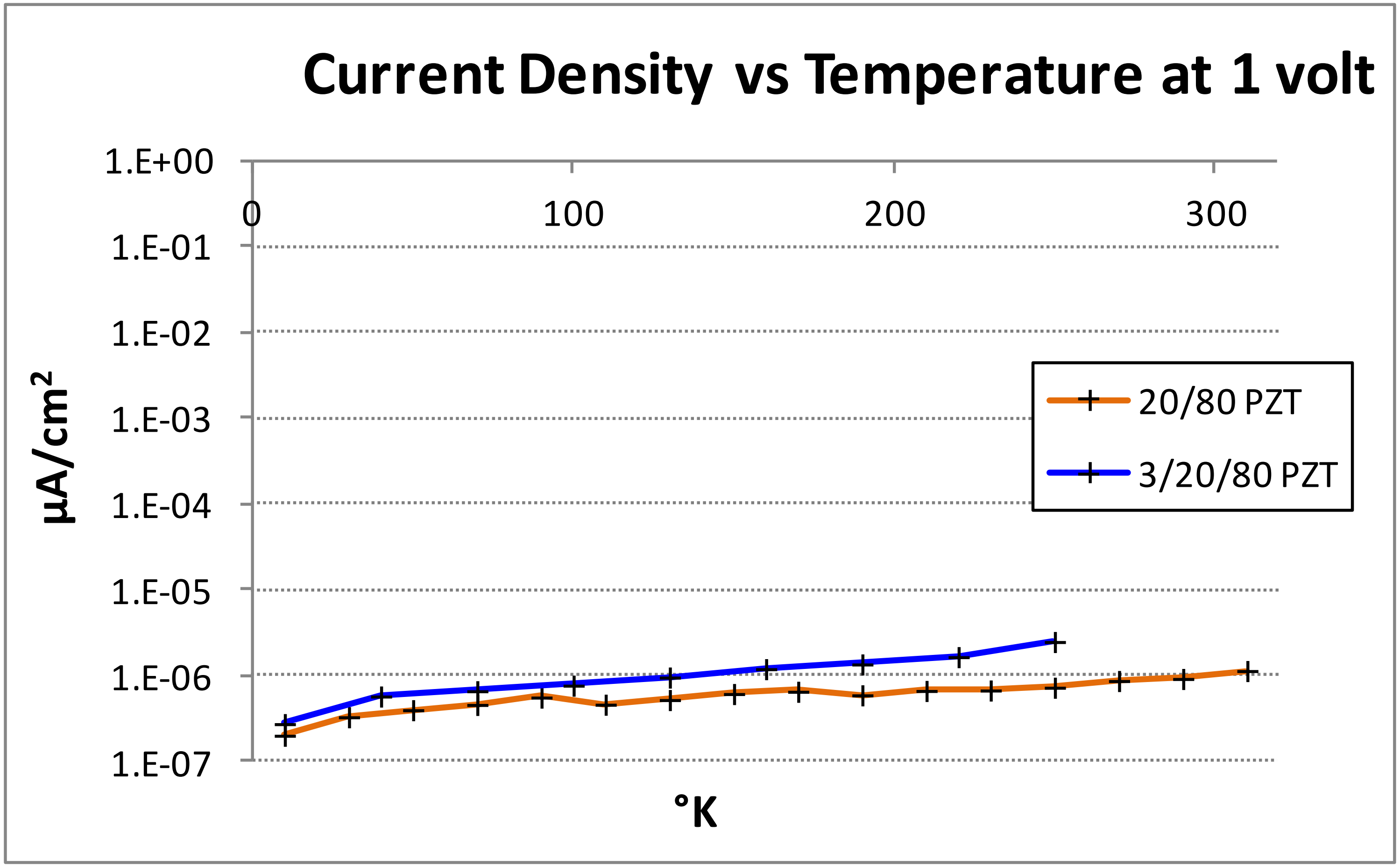
## 40,000 $\mu m^2$ 3/20/80 PNZT vs 20/80 PNZT




*Cryogenic temperatures do not appear to affect ferroelectric switching speed.*

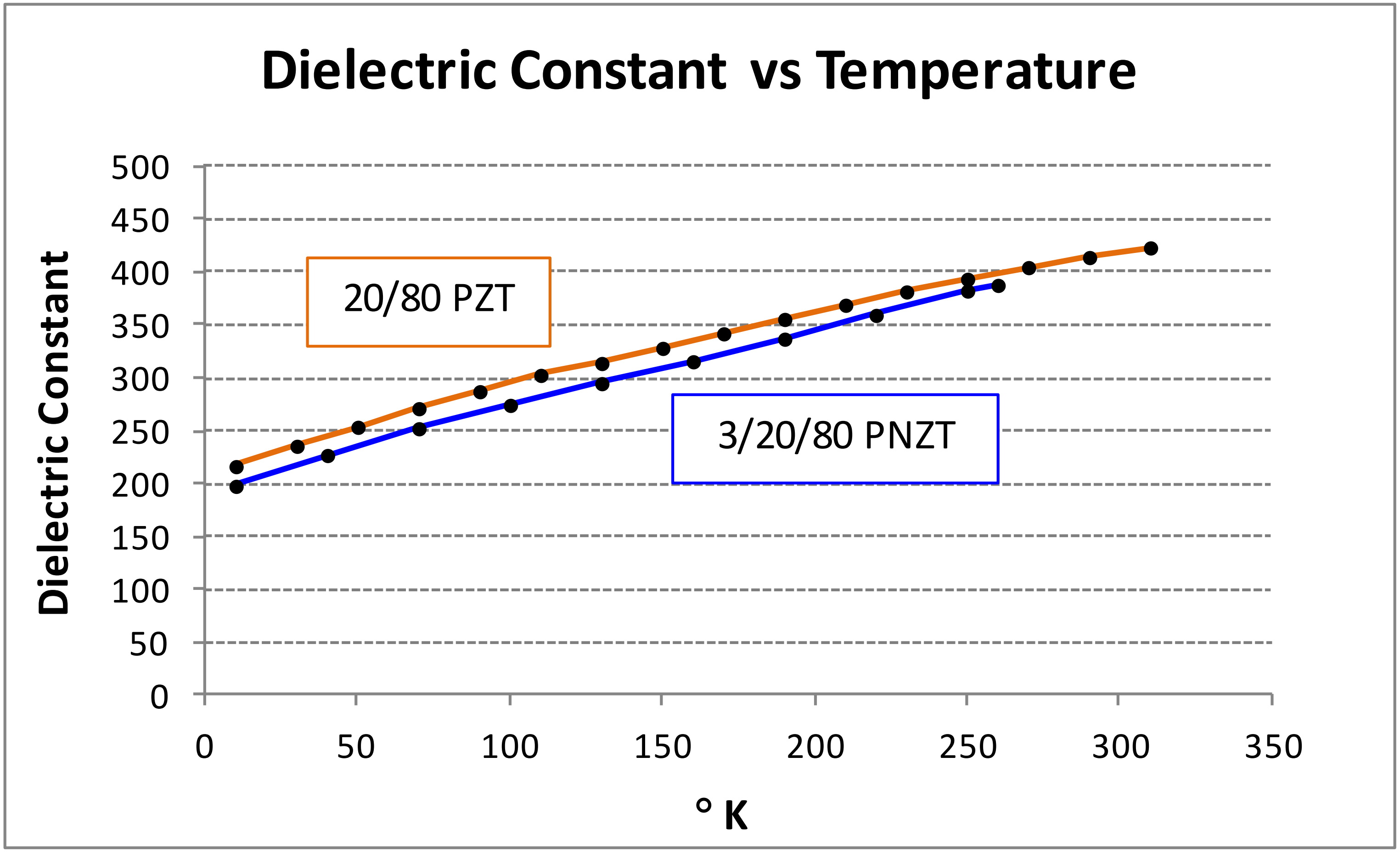
# Leakage vs Temperature

## 40,000 μm² 3/20/80 PNZT vs 20/80 PNZT



# Dielectric Constant vs Temperature

## 40,000 µm² 3/20/80 PNZT vs 20/80 PNZT



# Conclusions

- It appears that tetragonal PZT *does not have a phase boundary* from room temperature down to 5 K.
- Of the parameters of the hysteresis loop for both undoped and niobium-doped PZT, *only the coercive voltages change significantly with temperature.*
- Switching speed for both compositions *is unaffected by temperature.*
- Leakage *decreases as temperatures decrease.*

# Conclusions

- Dielectric constant *decreases as temperature decreases*.
- Remanent polarization *increases as the temperature decreases.*
  - Switched polarization (P*) *increases* as temperature goes down.
  - Unswitched polarization (P^) *decreases* as temperature goes down.

*20/80 PZT and its niobium-doped cousins appear to remain fully functional as memory devices down to 5 K.*