High-Operating-Temperature Superconducting Nanowire Single Photon Detectors

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WSi Superconducting Nanowire Single Photon Detectors (SNSPD)

- High system detection efficiency: ~ 90% at 1550 nm wavelength
- Low jitter: 50 - 150 ps FWHM
- Low intrinsic dark count rate: ~ 1 cps
- Low reset time: ~ 25 ns
- High maximum count rate: 20 Mcps
- UV to mid-IR sensitivity

Marsili et al., Nature Photonics 7, 210 (2013)

Drawback: Low operating temperature: $T < 1$ K

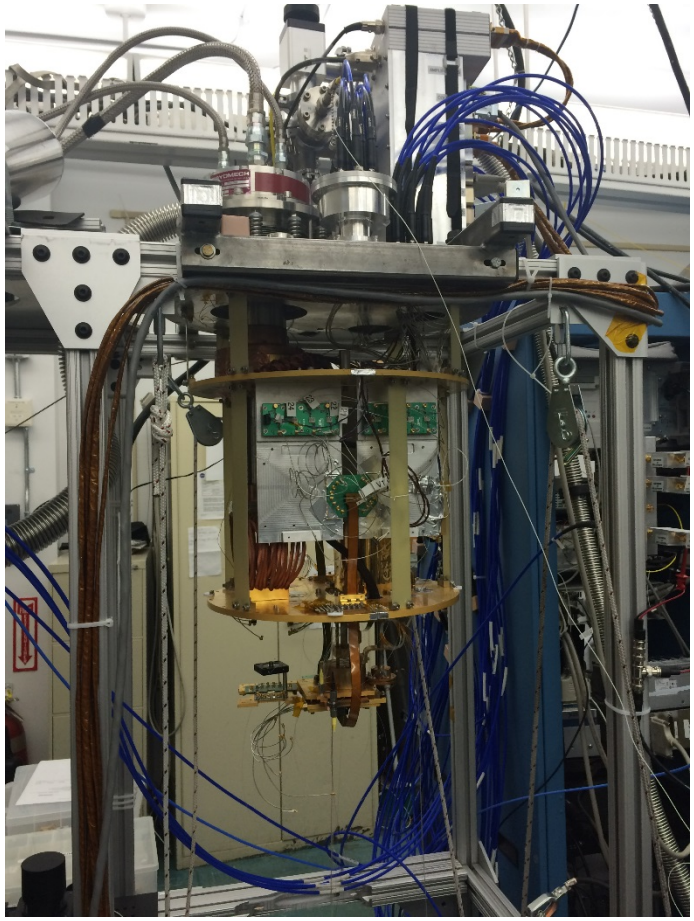
↓

Complex cryogenics

Refrigerator Comparison

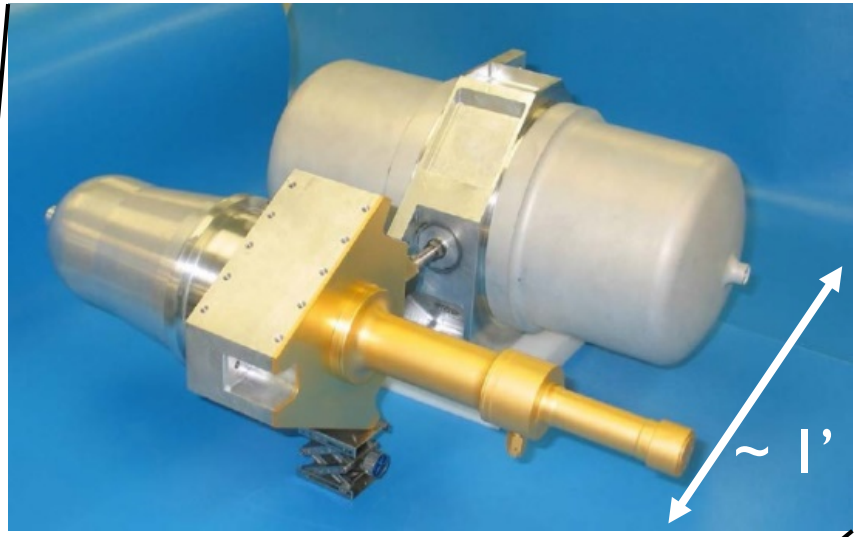
He^3/He^4 Sorption/Pulse Tube

~ 4.5’



T ~ 500 mK

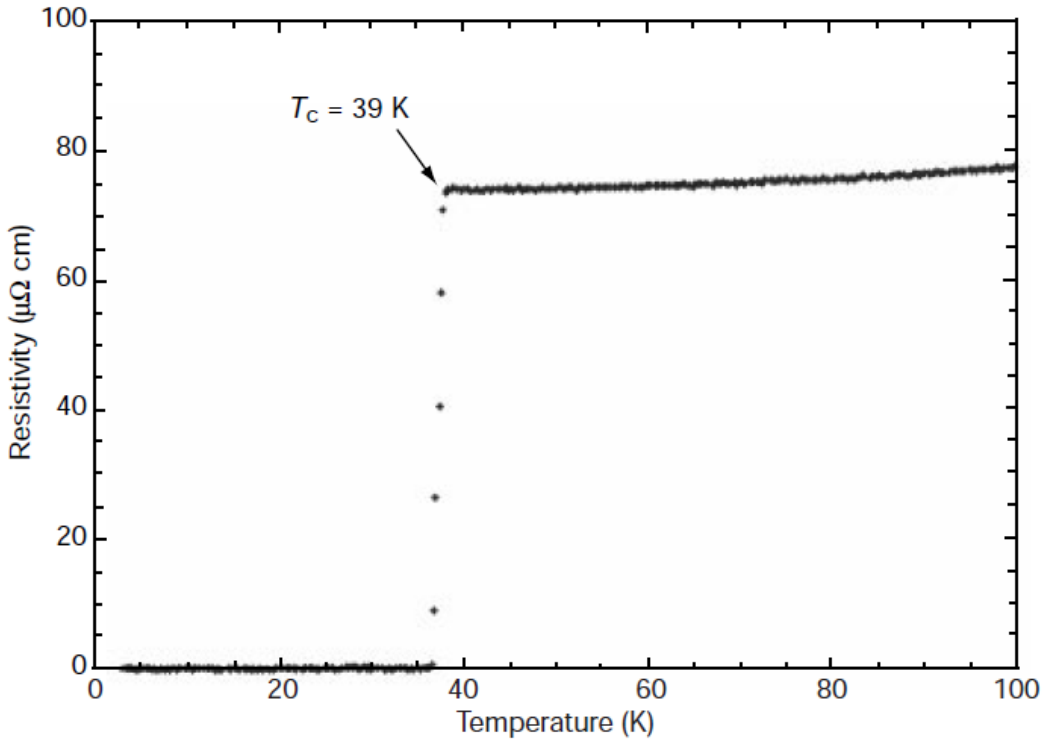
Stirling/Pulse Tube (Raytheon LT-RSP2)



T ~ 10 K

Our Approach: MgB_2 SNSPDs

- MgB_2 has bulk T_C ~ 40 K
- Well behaved, metallic superconductor
- SNSPDs may operate at 20 K where cryogenics is easy, cost effective, reliable, and compact



J. Nagamatsu et al., Nature **410** , 63-64 (2001)

Challenges of MgB_2 SNSPDs

- Difficult to grow high-quality MgB_2 thin films
- MgB_2 nanowire fabrication complex because:
  i. MgB_2 highly reactive with oxygen
  ii. MgB_2 etch limited to argon ion milling
- Single photon detection at 20 K never demonstrated

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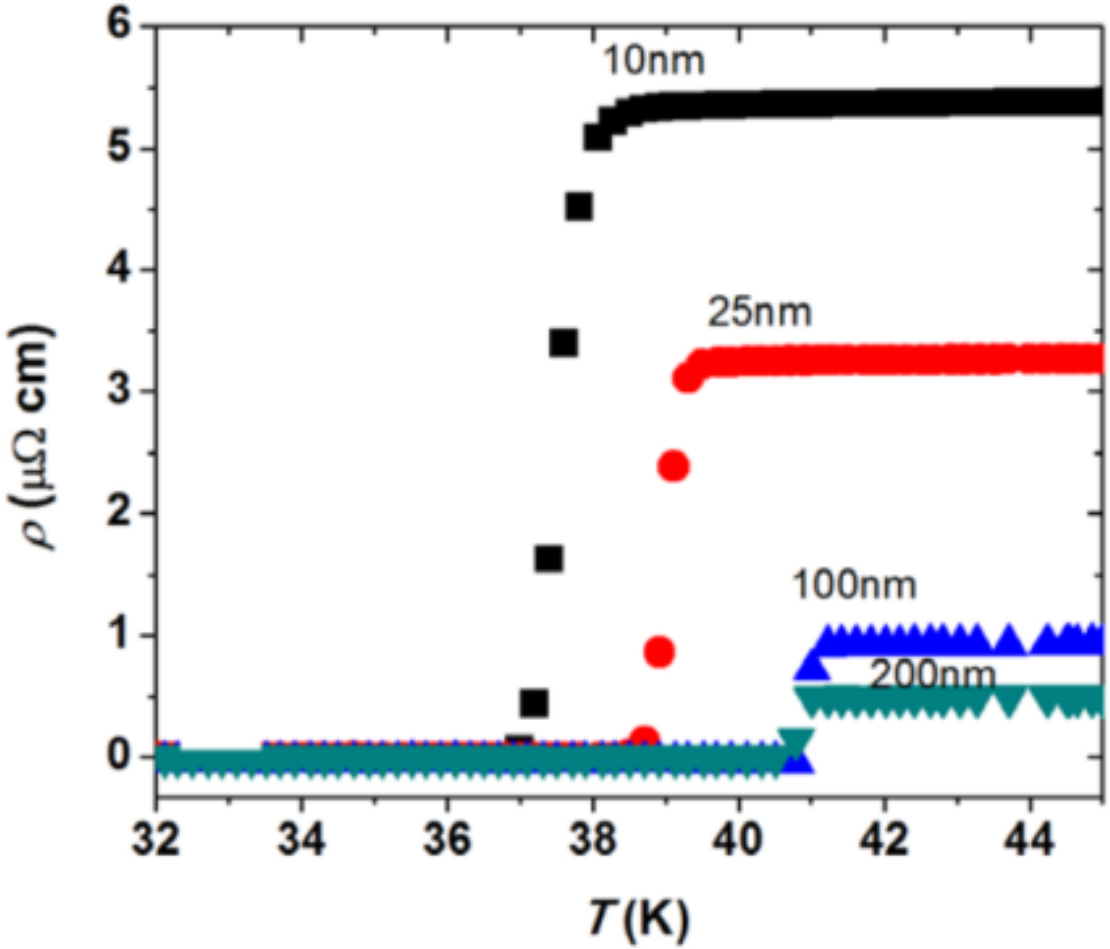
High Quality MgB_2 Thin Films

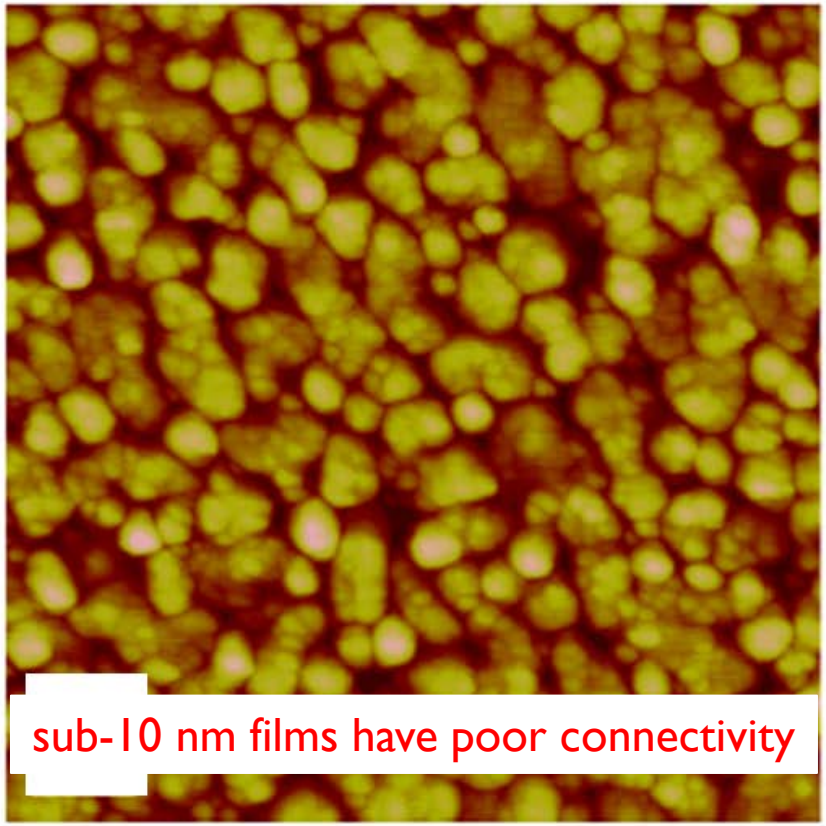
Hybrid Physical-Chemical Deposition (HPCVD)



C. Zhuang *et al.*, Supercond. Sci. Technol. **23** (5), 055004 (2010)

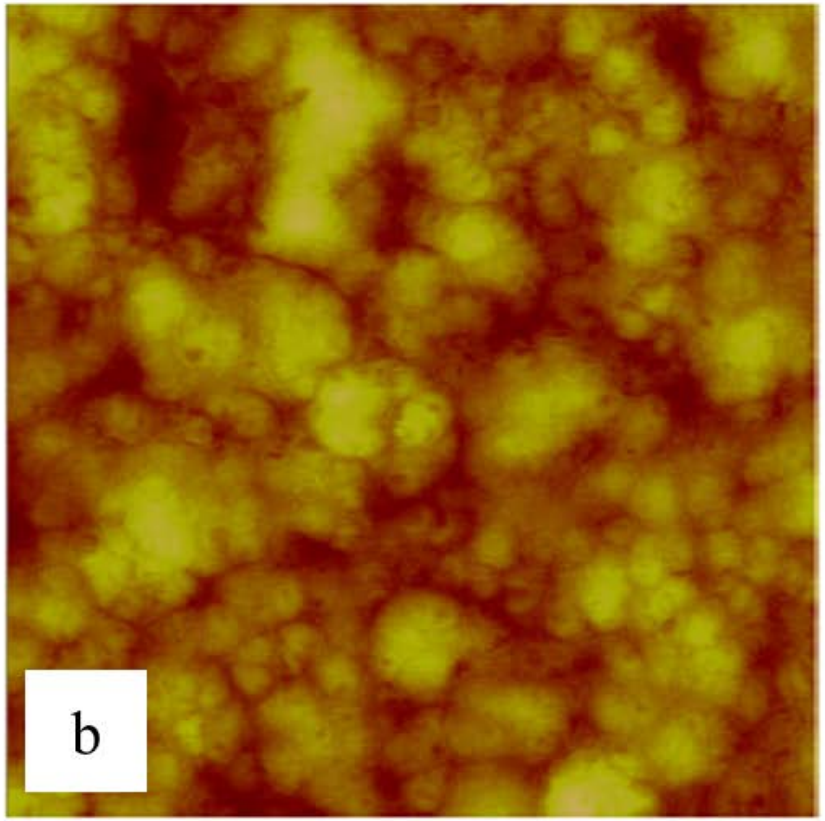
Problem with sub-10 nm films

d = 7.5 nm



1 μm

d = 25 nm

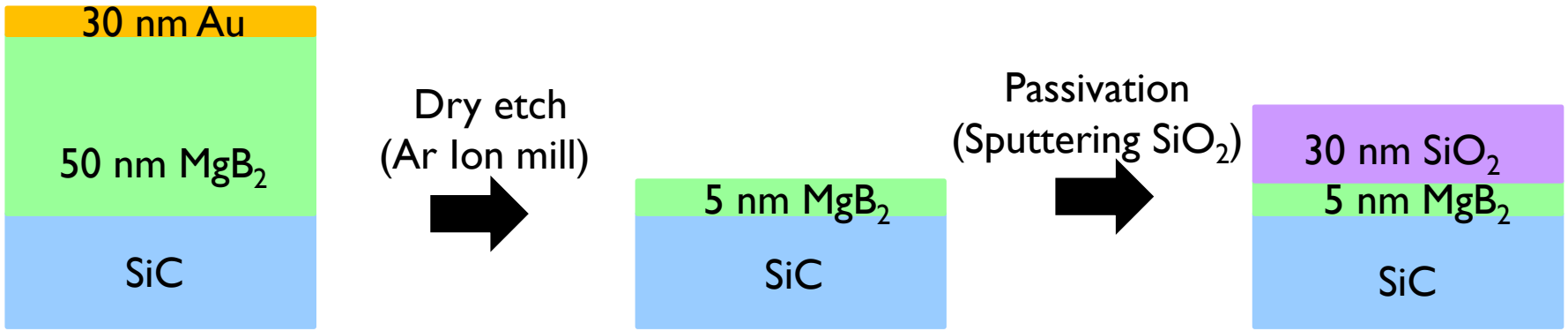


1 μm

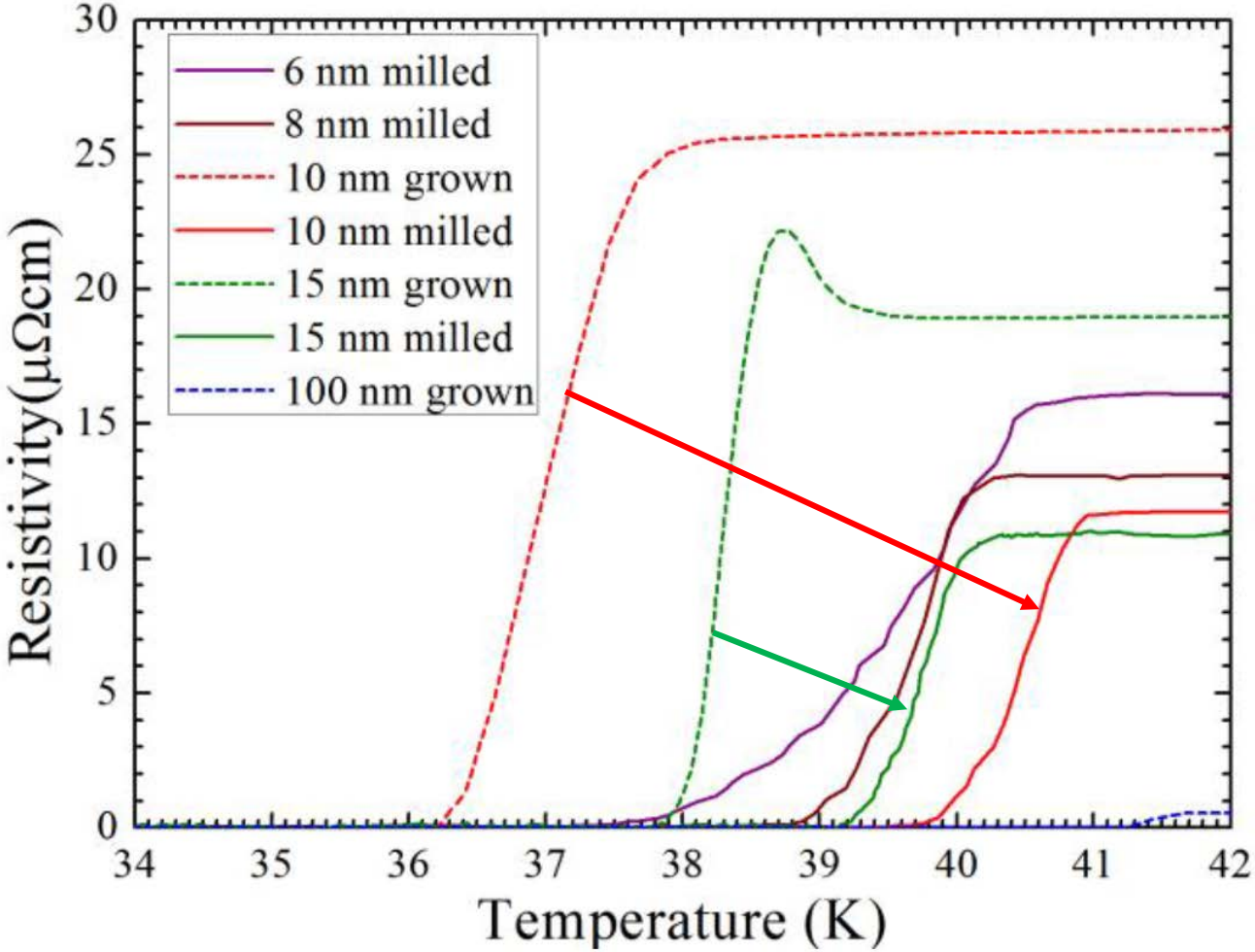
C. Zhuang *et al.*, Supercond. Sci. Technol. **23** (5), 055004 (2010)

Thin Film Fabrication Process

Etch-back technique achieves high-quality sub-10 nm films

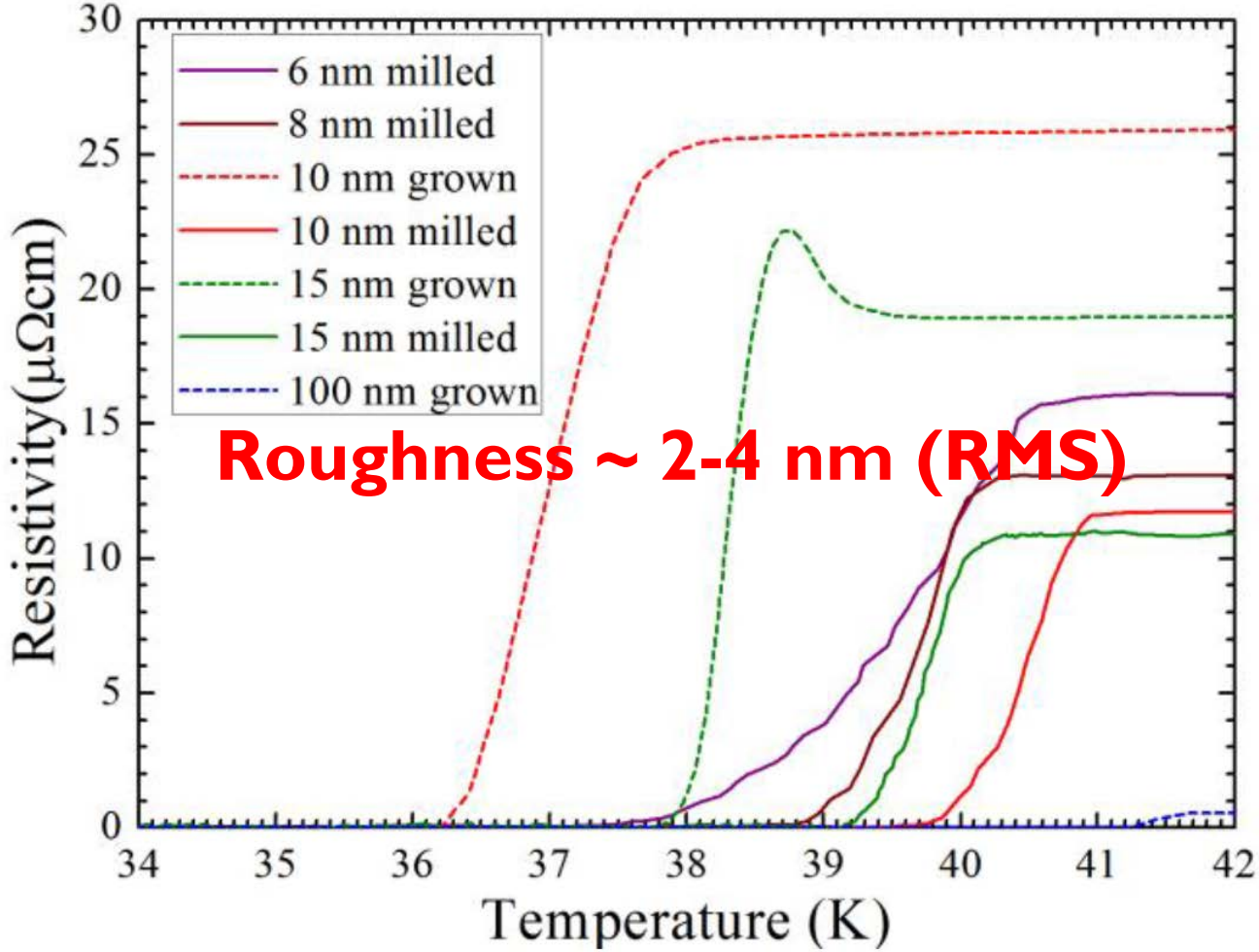


Preliminary Results



M.A. Wolak et al., IEEE Trans. Appl. Supercond. **25,** 3 7500905 (2015)

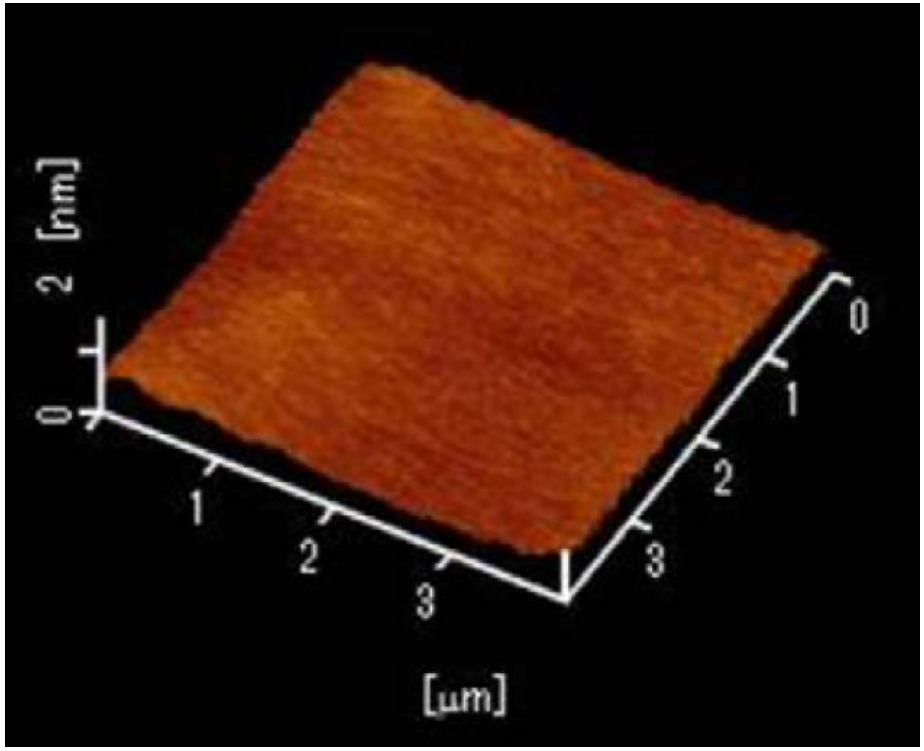
Preliminary Results

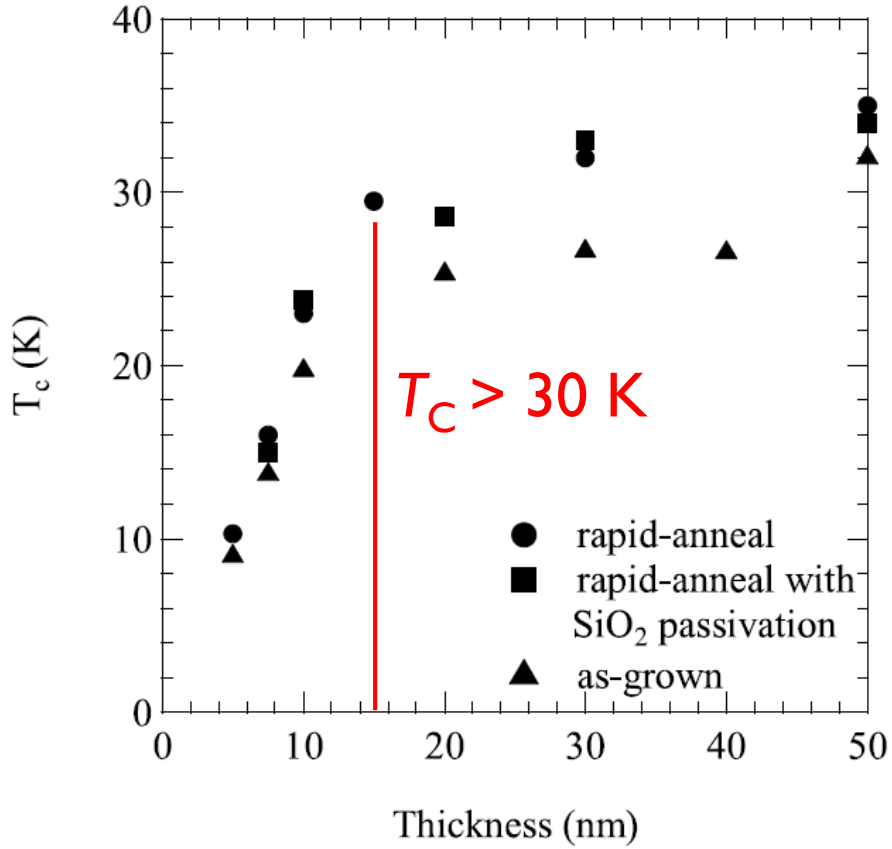


M.A. Wolak et al., IEEE Trans. Appl. Supercond. **25,** 3 7500905 (2015)

Molecular Beam Epitaxy films

Rapid Annealing





Roughness = 0.35 nm (RMS)

H. Shibata et al., Supercond. Sci. Technol. **26** (2013) 035005

Film comparison

	Roughness (RMS)	T_C (~6 nm)
MBE	<0.35 nm	10 K
HPCVD	2-4 nm	39 K

Challenges of MgB_2 SNSPDs

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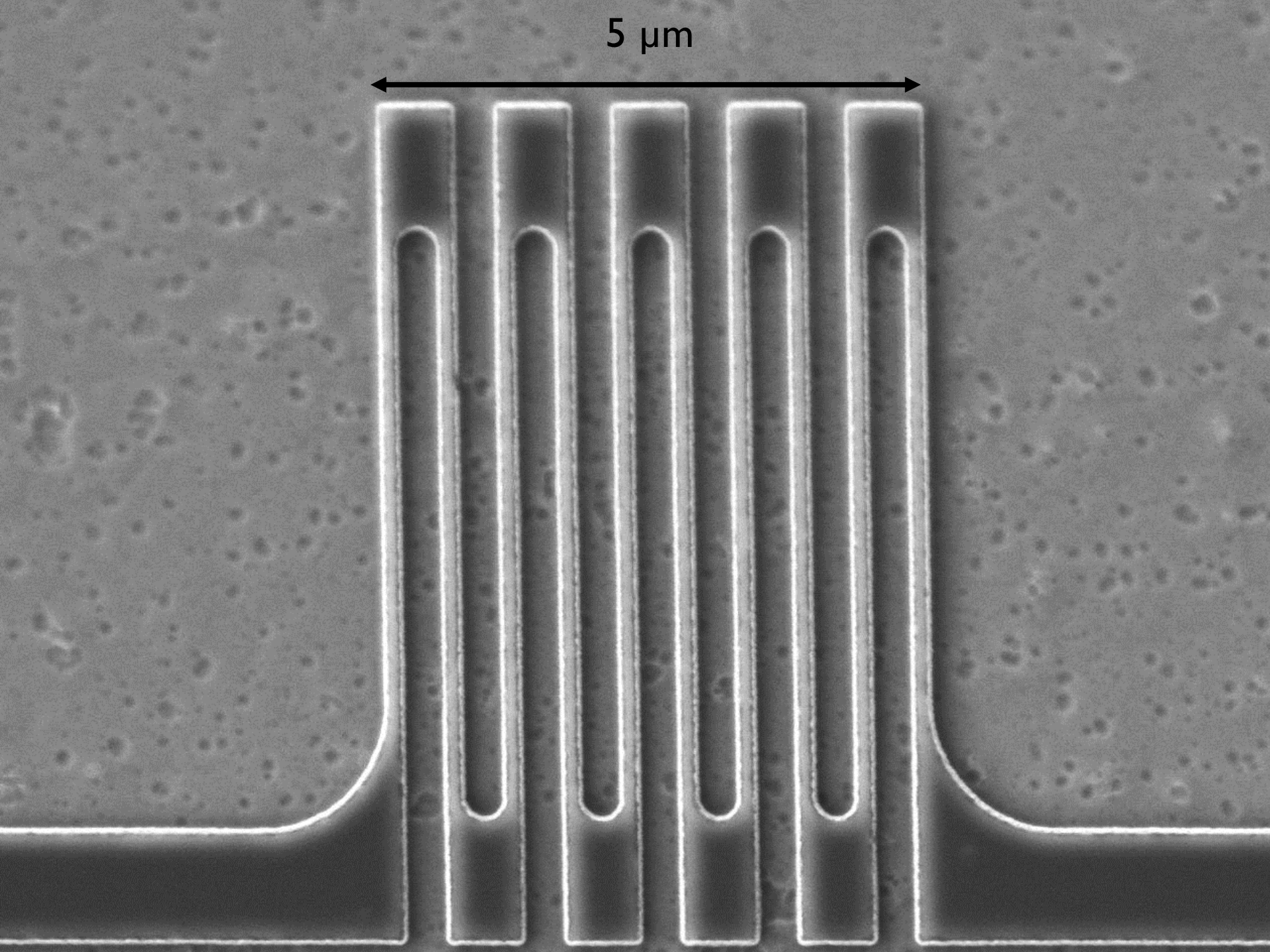
- Single photon detection at 20 K never demonstrated


5 µm

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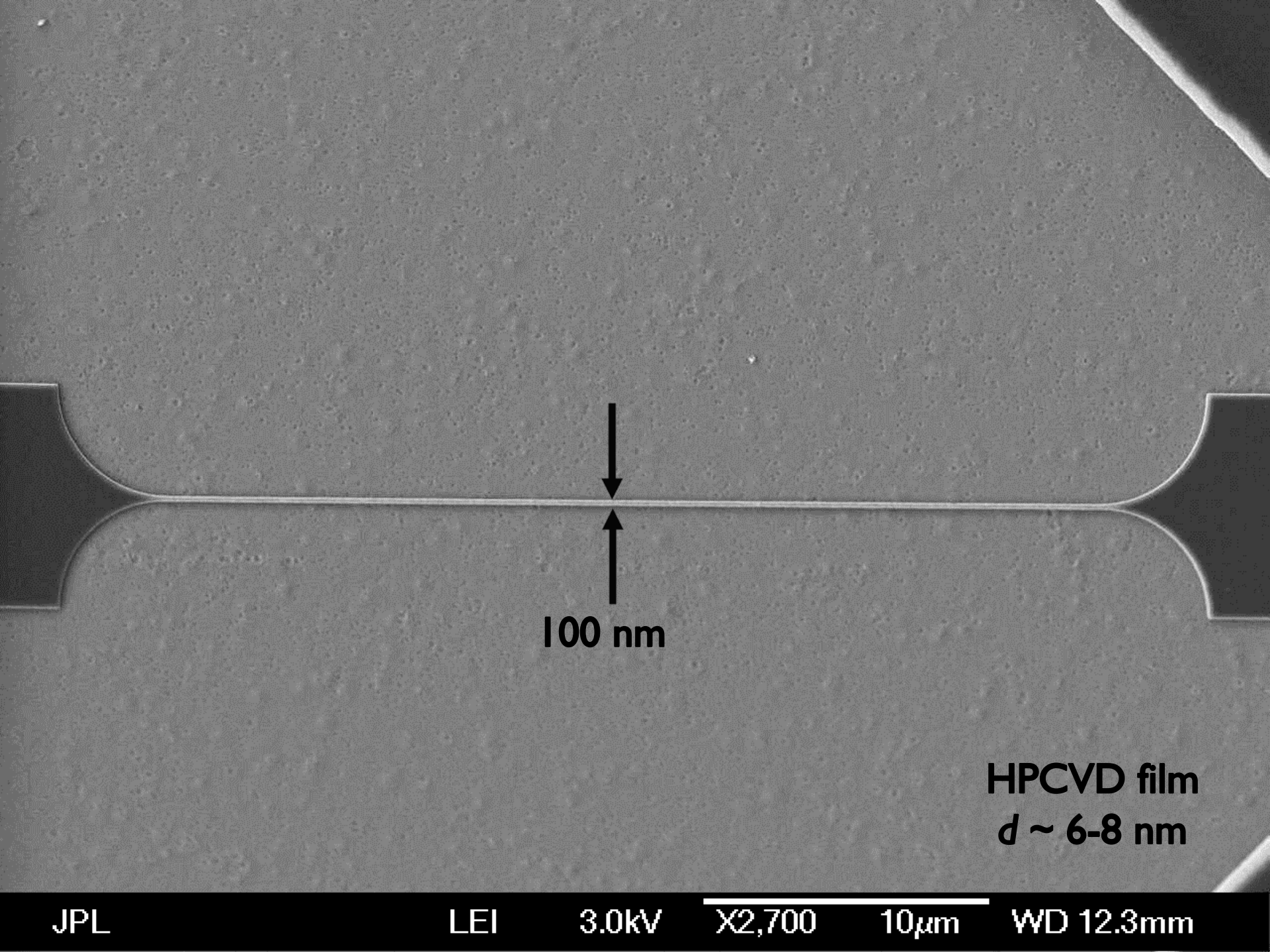
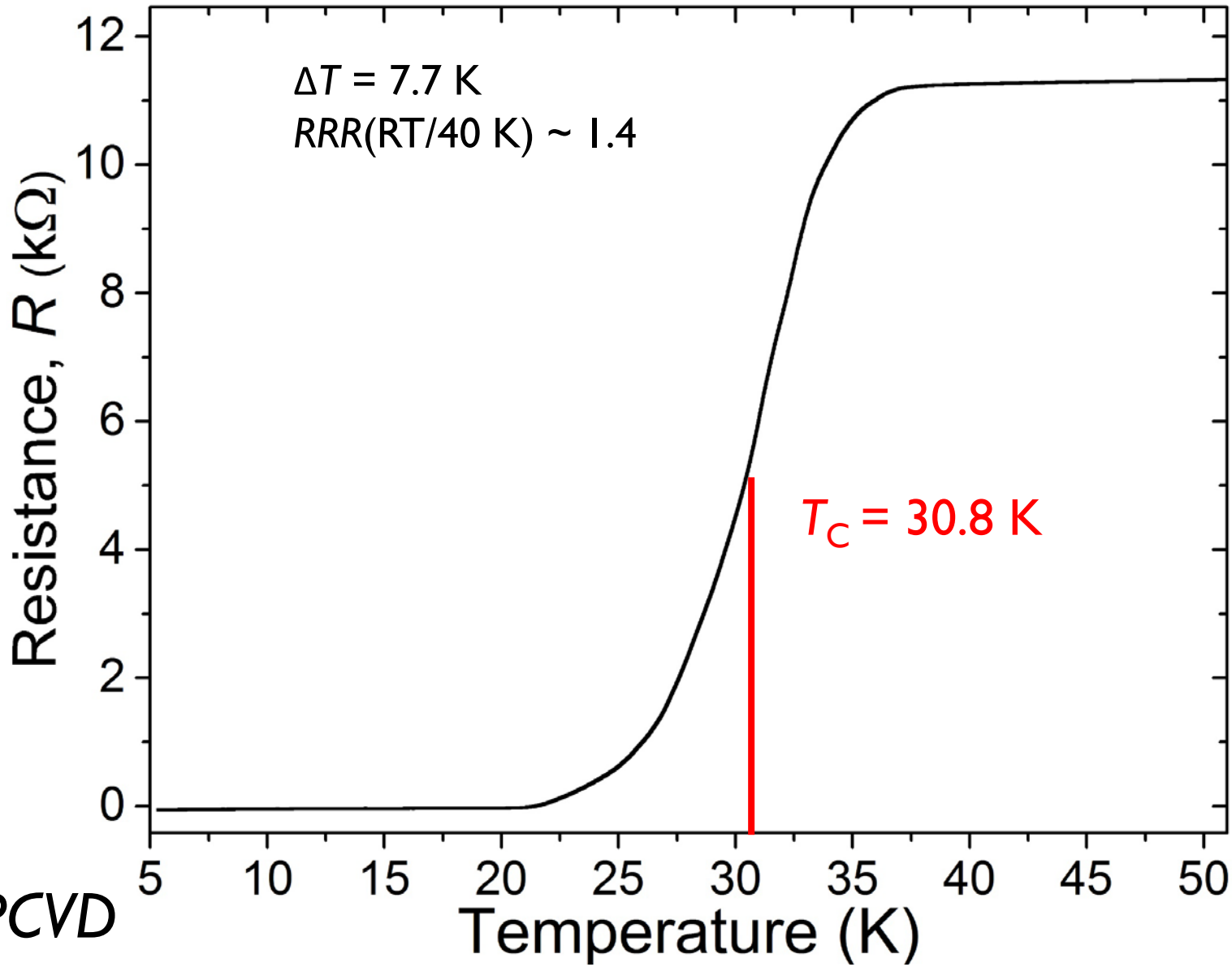
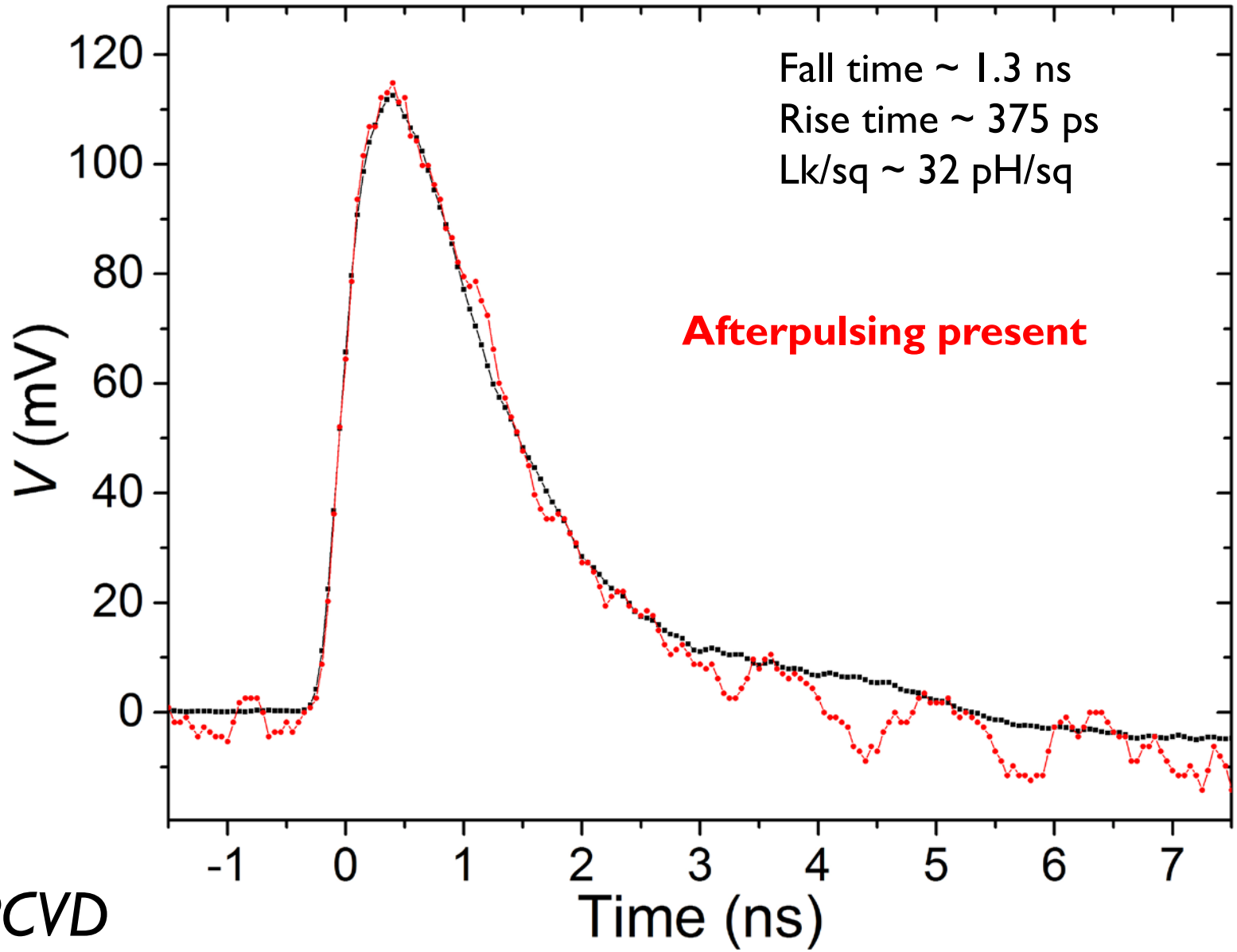

100 nm
HPCVD film
d ~ 6-8 nm
JPL
LEI
3.0kV
X2,700
10μm
WD 12.3mm

Transition Temperature, T_C



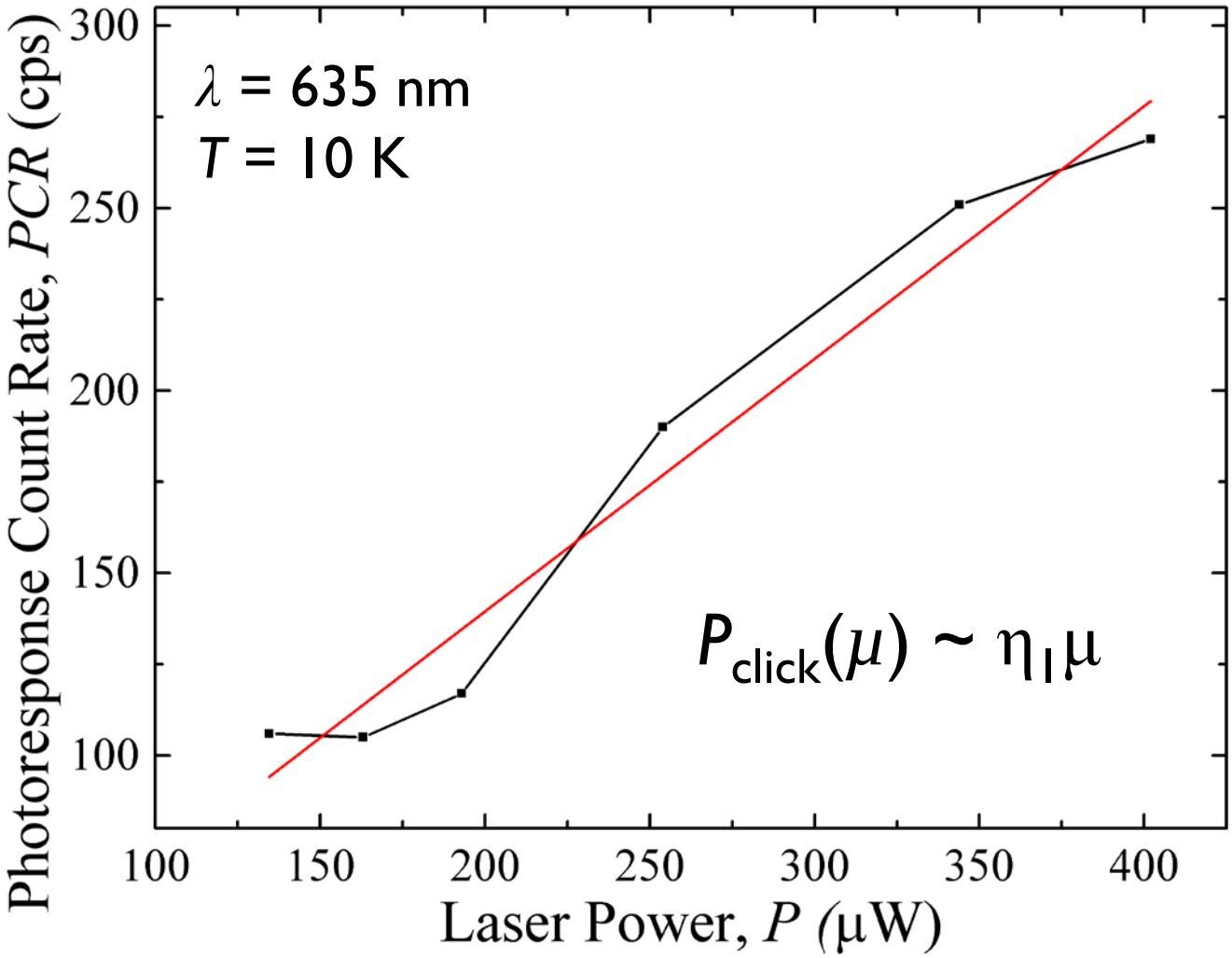
HPCVD

Photoresponse pulse

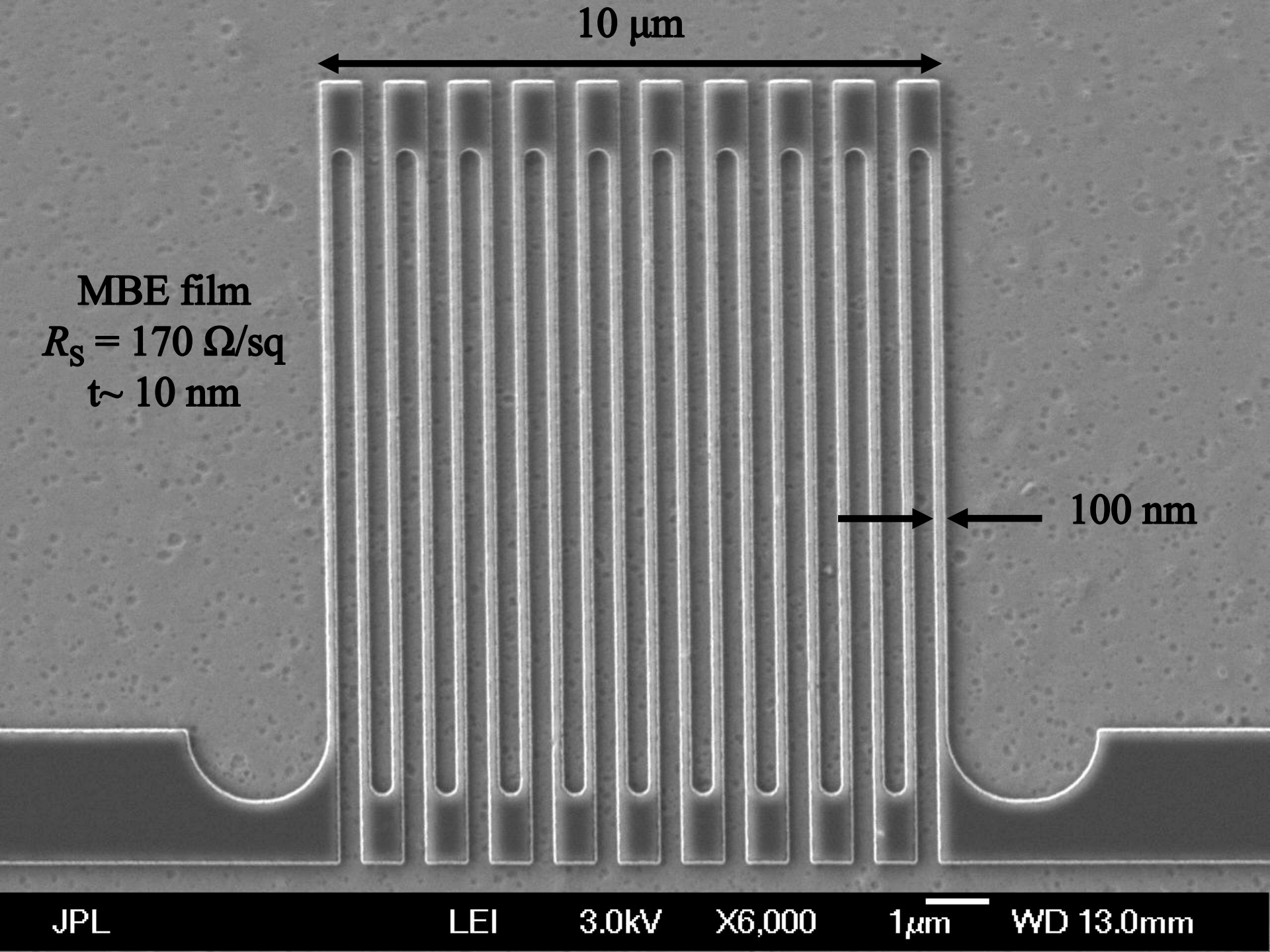


HPCVD

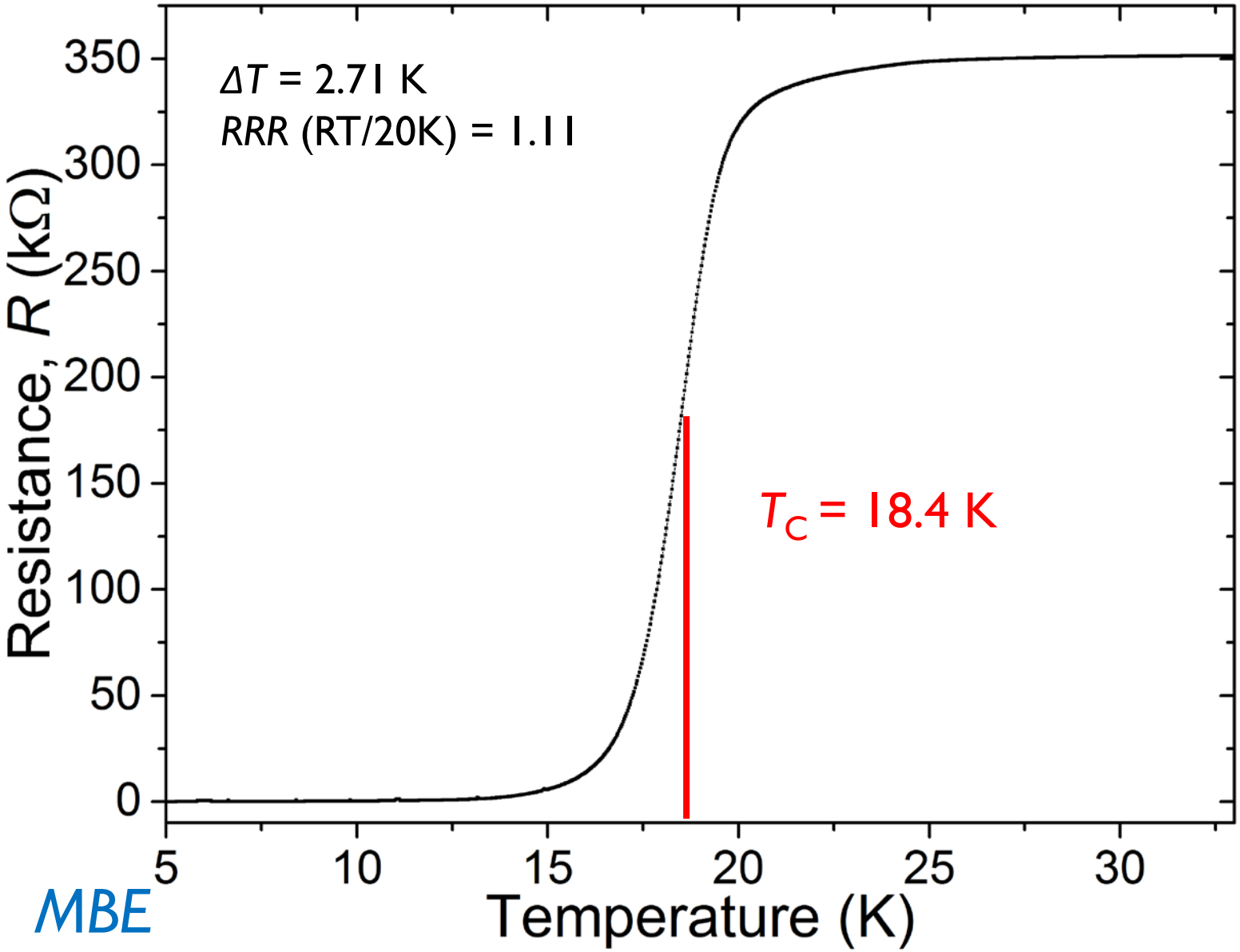
Single Photon Detection at 10 K!



HPCVD

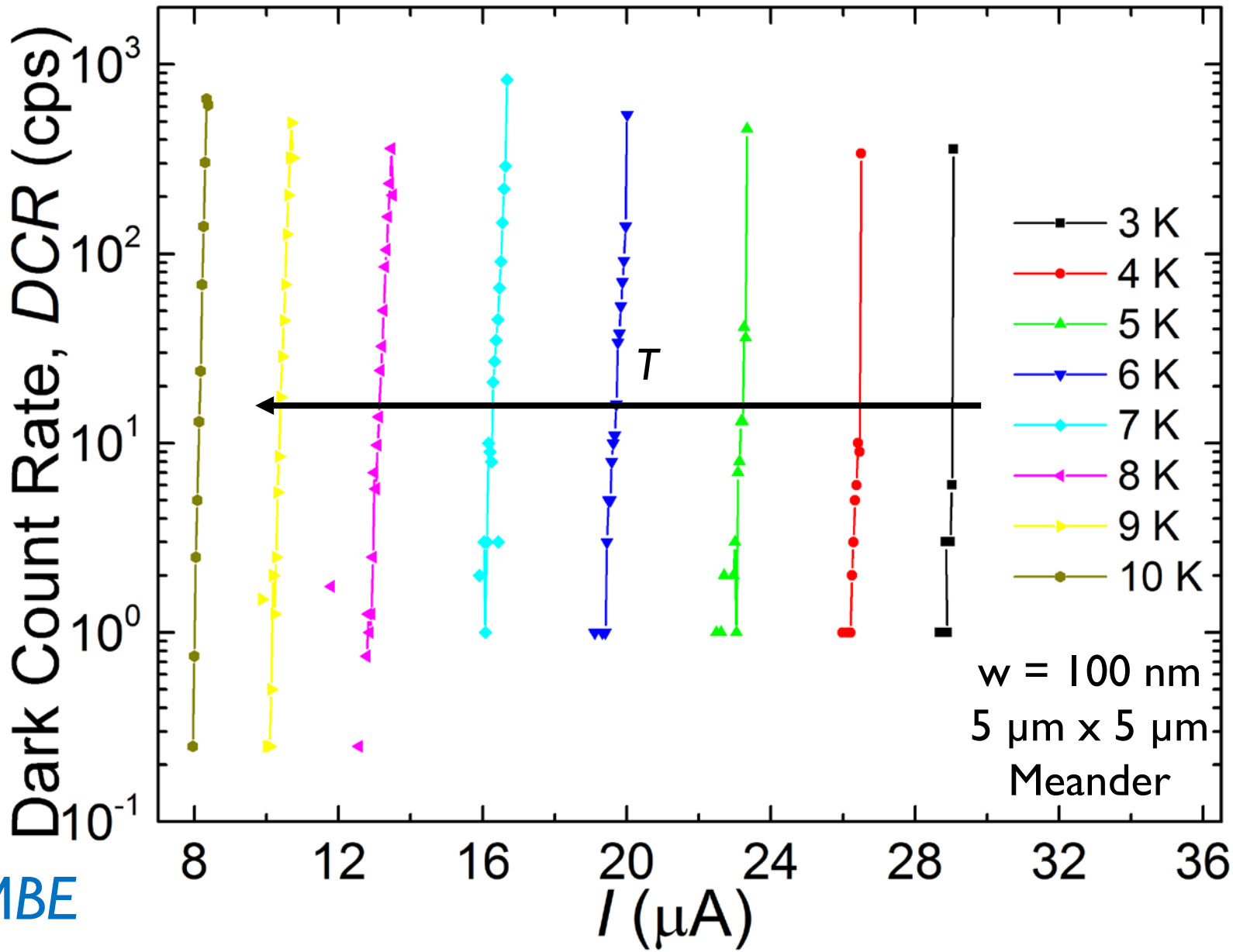

10 μm
MBE film
R_S = 170 Ω/sq
t~ 10 nm
100 nm
JPL
LEI
3.0kV
X6,000
1μm
WD 13.0mm

Transition temperature, T_C



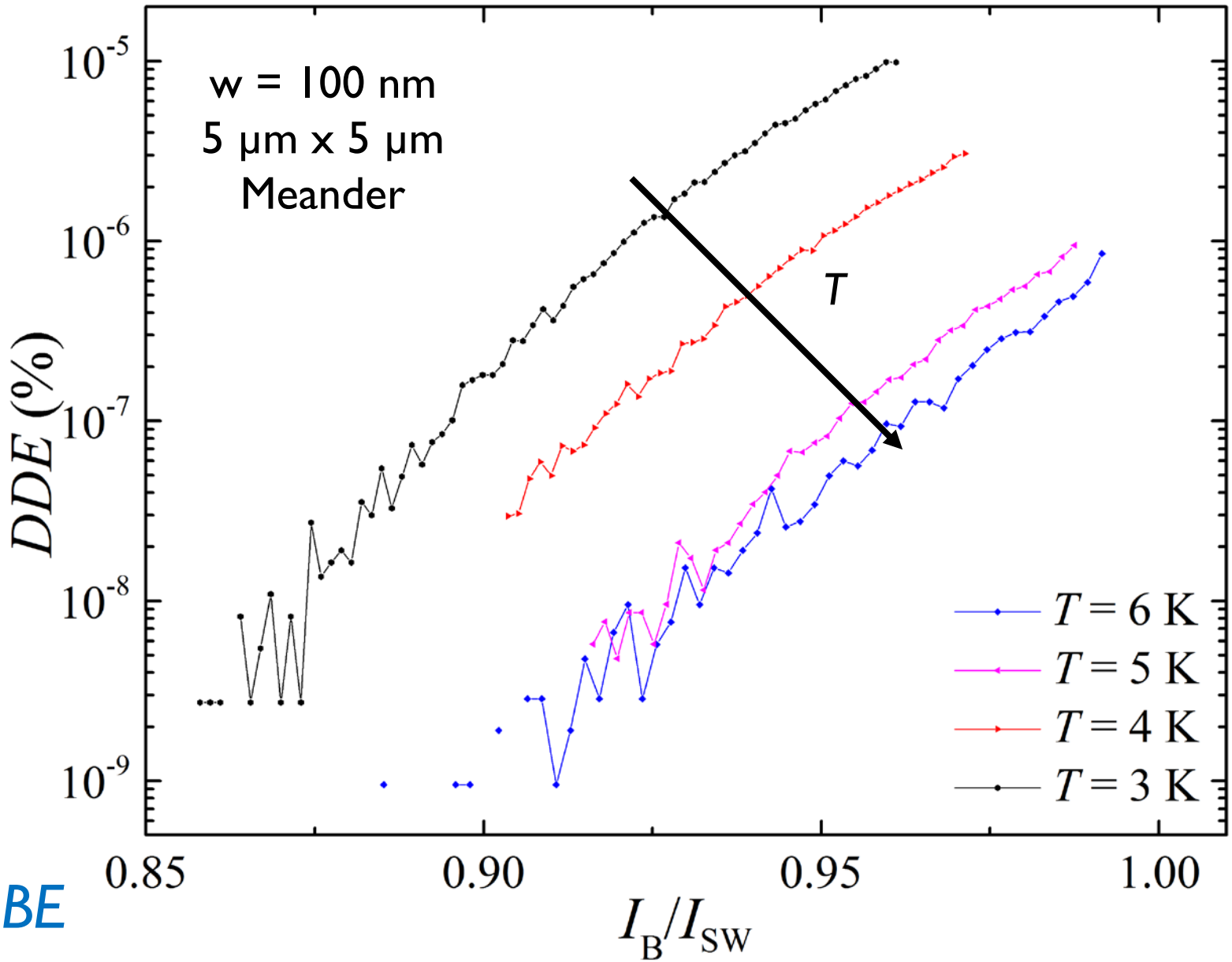
MBE

Dark count rate, *DCR*



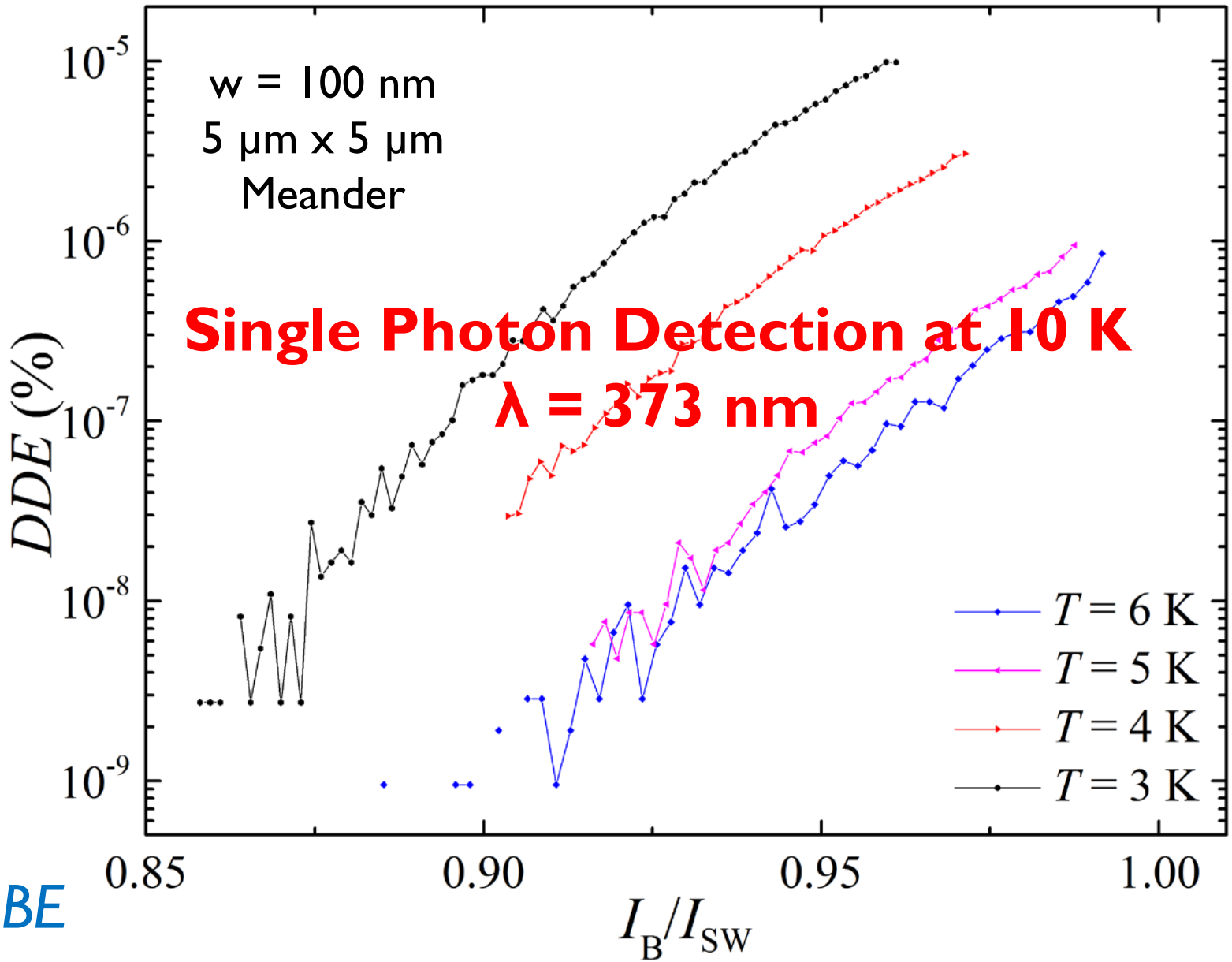
MBE

Device detection efficiency at 1550 nm



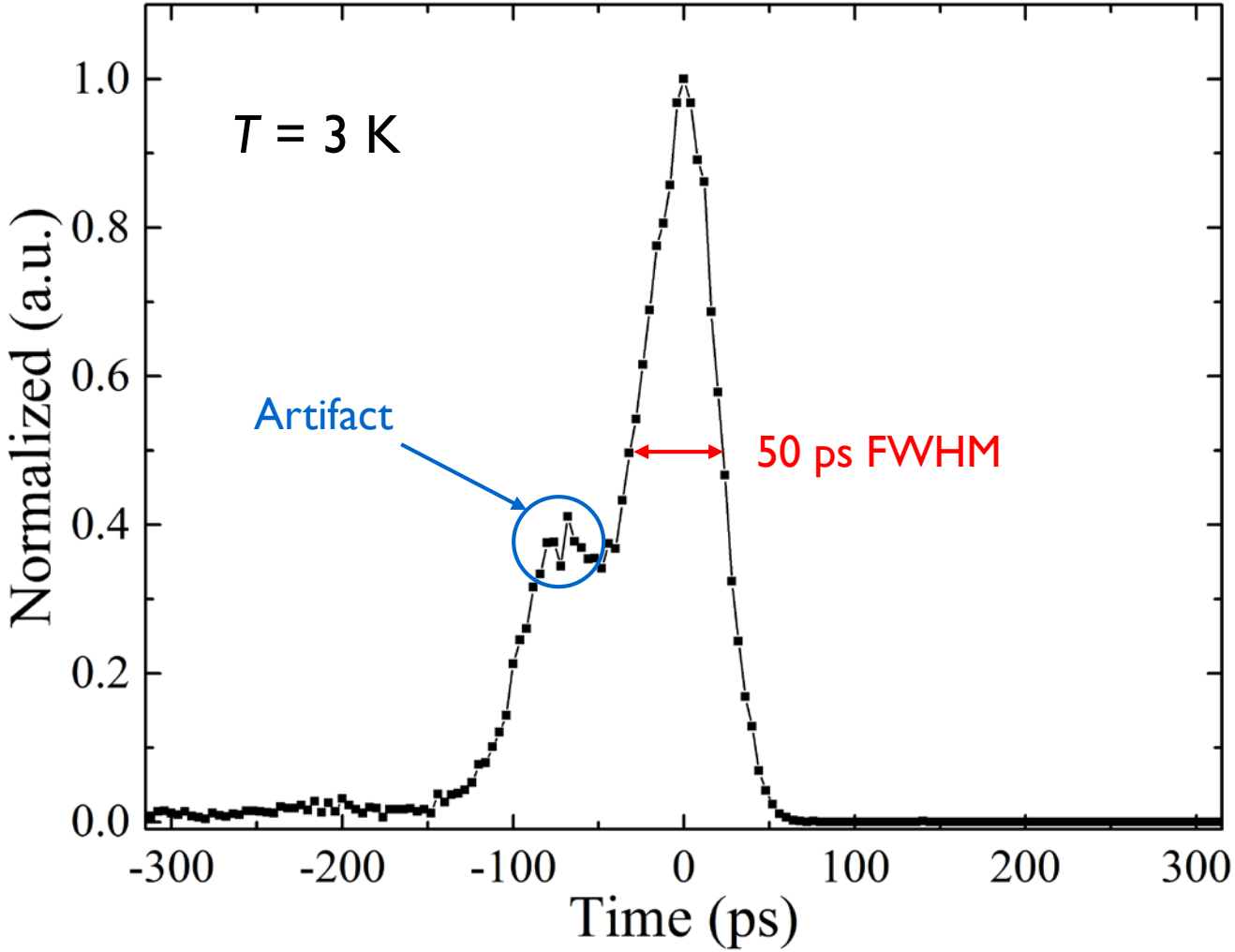
MBE

Device detection efficiency at 1550 nm

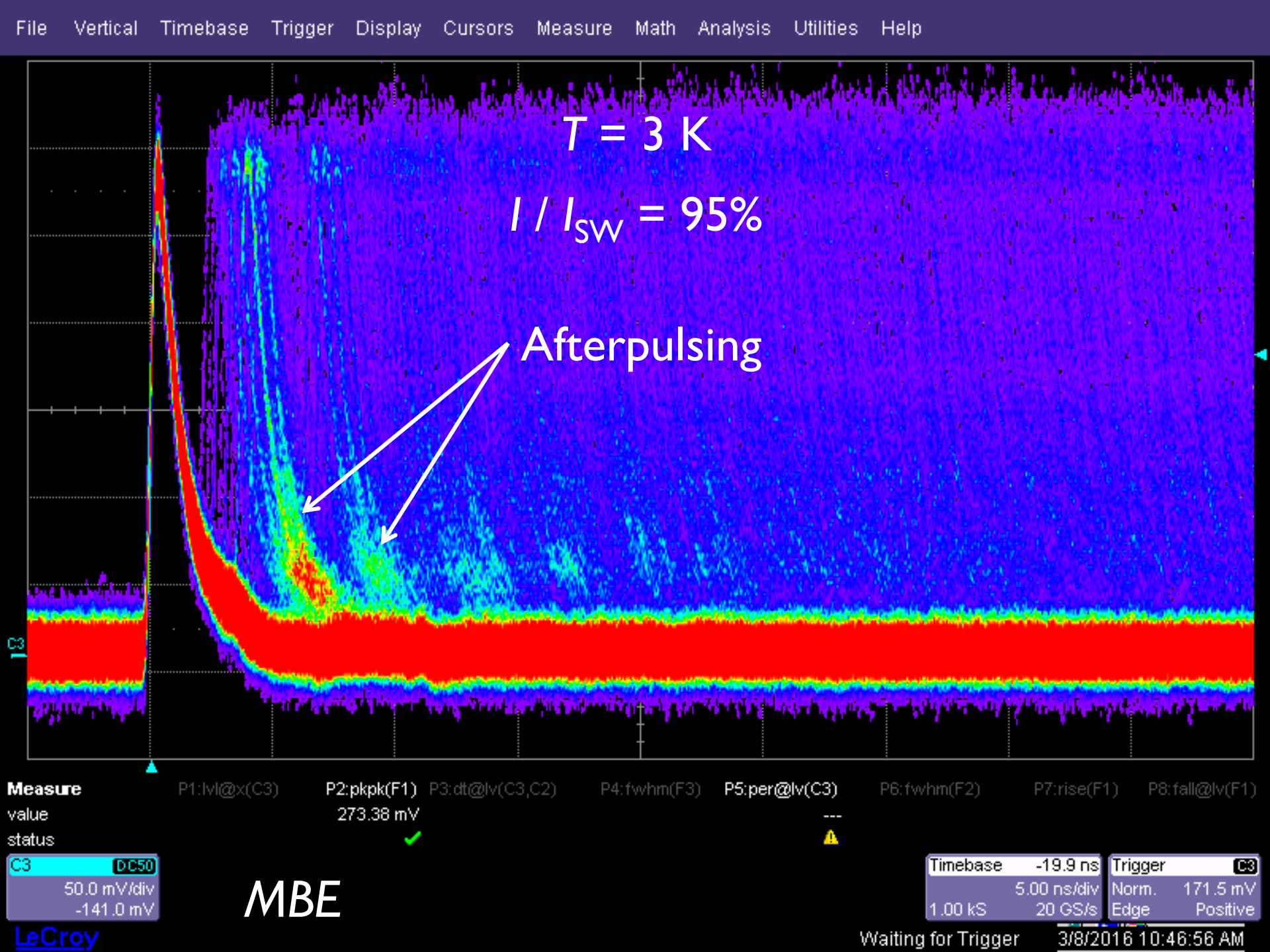


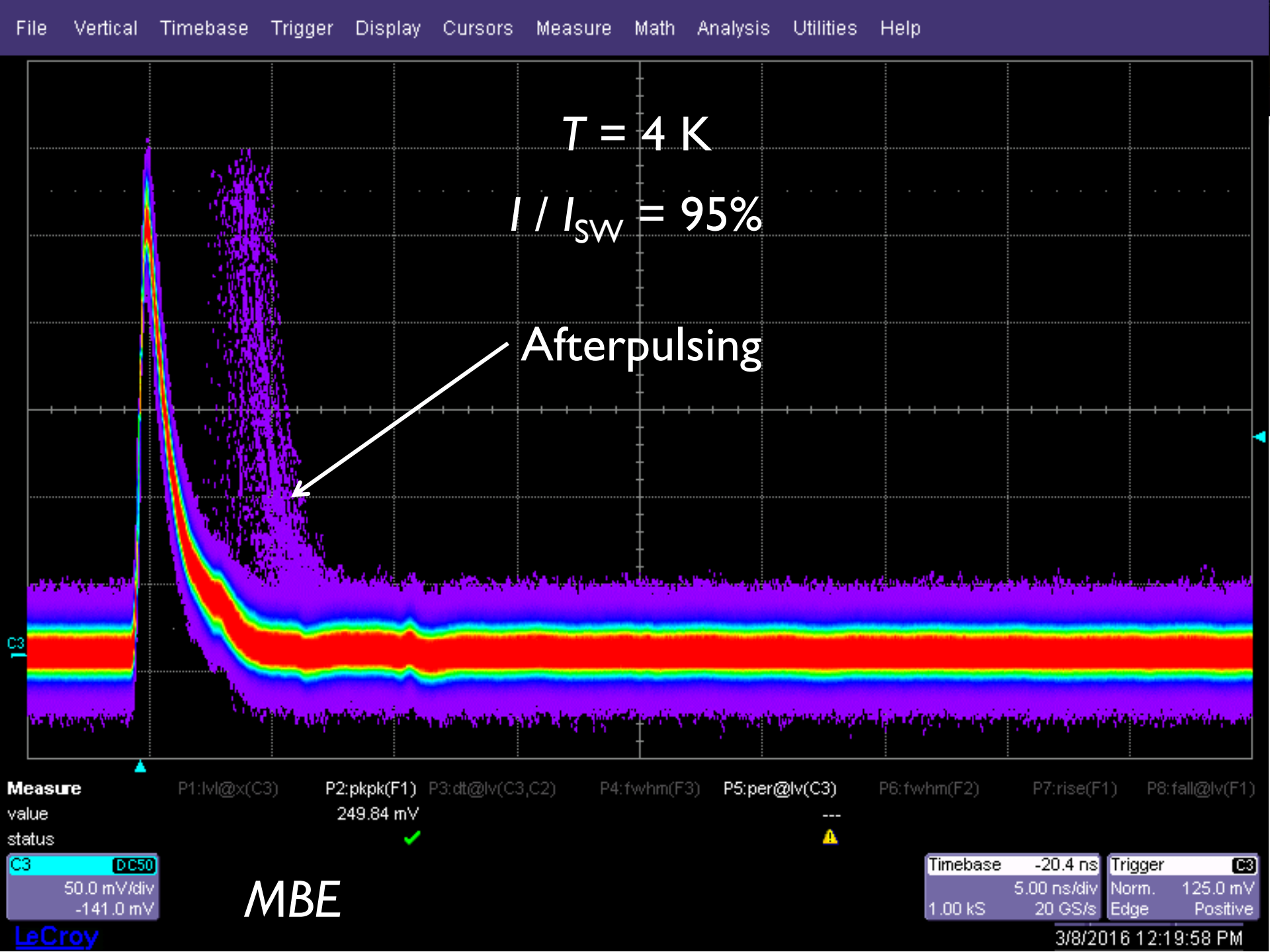
MBE

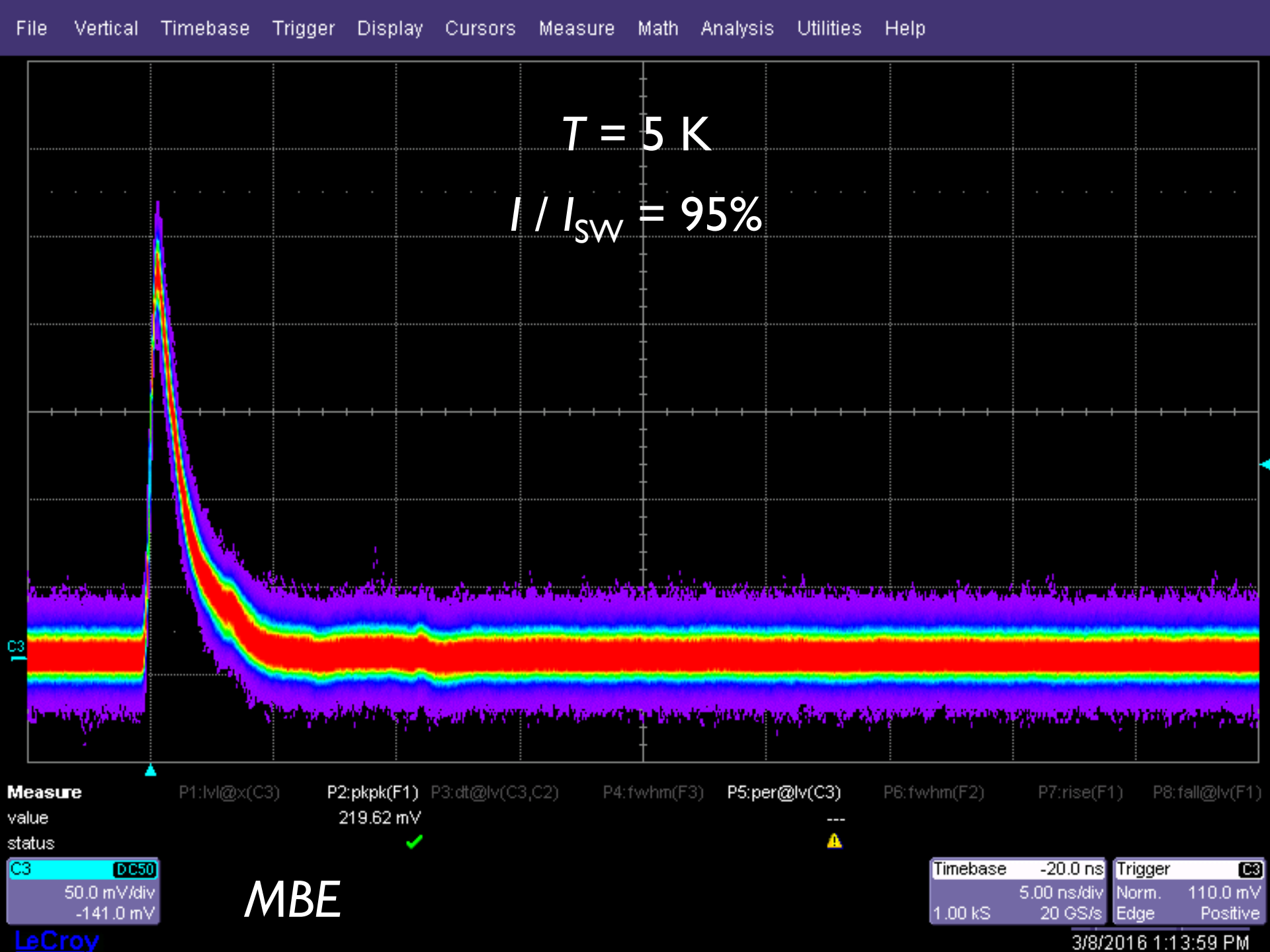
Instrument response function

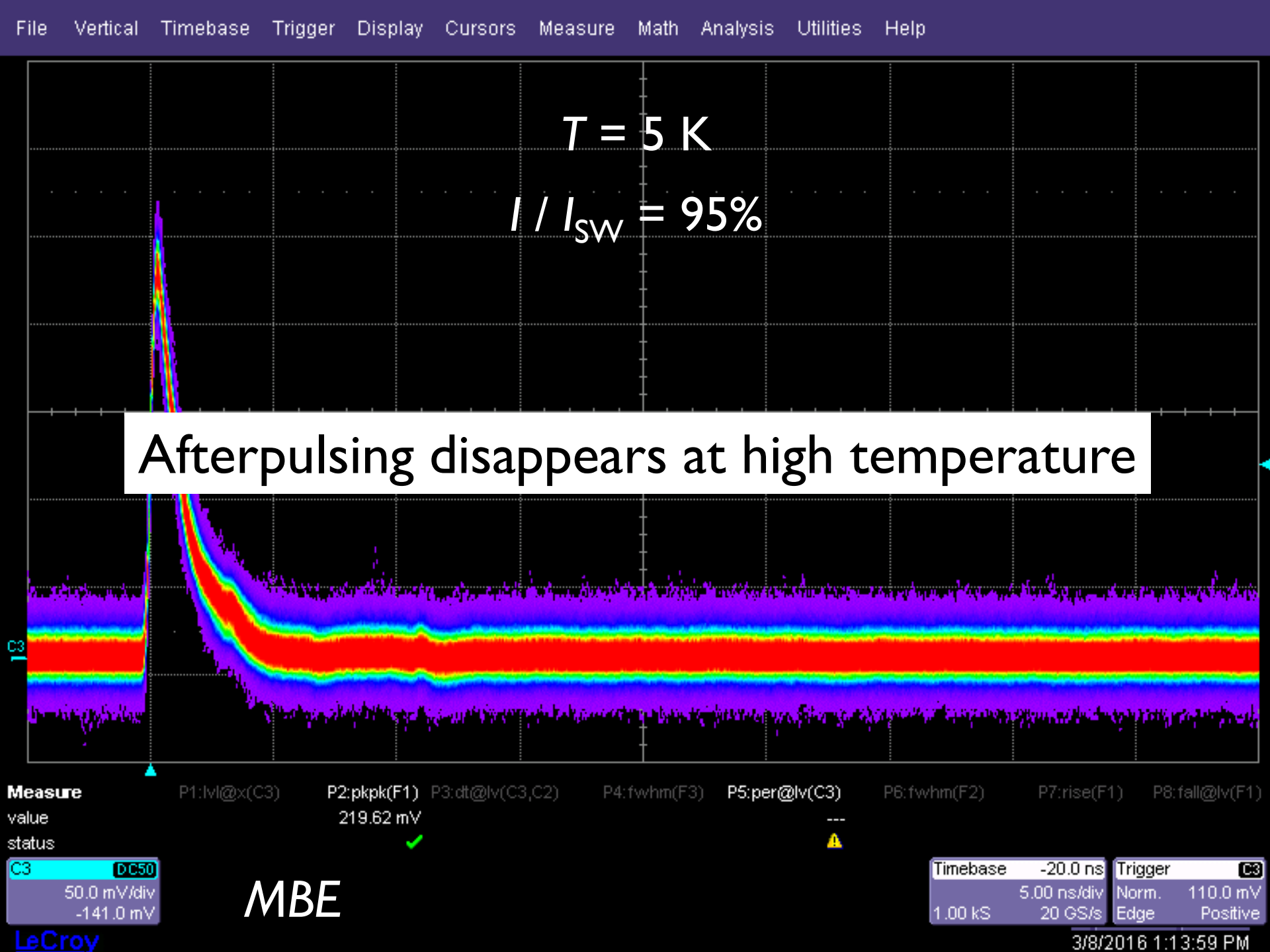


MBE


File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
T = 3 K
I / I_SW = 95%
Afterpulsing
C3
Measure
P1:lvl@x(C3)
P2:pkpk(F1)
P3:dt@lv(C3,C2)
P4:fwhm(F3)
P5:per@lv(C3)
P6:fwhm(F2)
P7:rise(F1)
P8:fall@lv(F1)
value
273.38 mV
---
status
C3 DC50
50.0 mV/div
-141.0 mV
MBE
Timebase -19.9 ns
5.00 ns/div
1.00 kS 20 GS/s
Trigger C3
Norm. 171.5 mV
Edge Positive
LeCroy
Waiting for Trigger
3/8/2016 10:46:56 AM


File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
T = 4 K
I / I_SW = 95%
Afterpulsing
C3
Measure
P1:lvl@x(C3)
P2:pkpk(F1)
P3:dt@lv(C3,C2)
P4:fwhm(F3)
P5:per@lv(C3)
P6:fwhm(F2)
P7:rise(F1)
P8:fall@lv(F1)
value
249.84 mV
---
status
C3 DC50
50.0 mV/div
-141.0 mV
MBE
Timebase -20.4 ns
5.00 ns/div
1.00 kS 20 GS/s
Trigger C3
Norm. 125.0 mV
Edge Positive
LeCroy
3/8/2016 12:19:58 PM


File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
T = 5 K
I / I_SW = 95%
C3
Measure
P1:lvl@x(C3)
P2:pkpk(F1)
P3:dt@lv(C3,C2)
P4:fwhm(F3)
P5:per@lv(C3)
P6:fwhm(F2)
P7:rise(F1)
P8:fall@lv(F1)
value
219.62 mV
---
status
C3 DC50
50.0 mV/div
-141.0 mV
MBE
Timebase -20.0 ns
5.00 ns/div
1.00 kS 20 GS/s
Trigger C3
Norm. 110.0 mV
Edge Positive
LeCroy
3/8/2016 1:13:59 PM


File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help
T = 5 K
I / I_SW = 95%
Afterpulsing disappears at high temperature
C3
Measure
P1:lvl@x(C3)
P2:pkpk(F1)
P3:dt@lv(C3,C2)
P4:fwhm(F3)
P5:per@lv(C3)
P6:fwhm(F2)
P7:rise(F1)
P8:fall@lv(F1)
value
219.62 mV
---
status
C3 DC50
50.0 mV/div
-141.0 mV
MBE
Timebase -20.0 ns
5.00 ns/div
1.00 kS 20 GS/s
Trigger C3
Norm. 110.0 mV
Edge Positive
LeCroy
3/8/2016 1:13:59 PM

Conclusion

- Fabrication of thin (< 10 nm) MgB_2 films with high critical temperature (T_C > 30 K)
- Fabrication of MgB_2 superconducting nanowires with high critical temperature (T_C > 30 K)
- Single-photon response up to 10 K temperature
- 50 ps FWHM jitter
- High speed operation may be possible at high temperature

End of Presentation