Jet Propulsion Laboratory
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THz heterodyne detectors based on MgB_2 thin films

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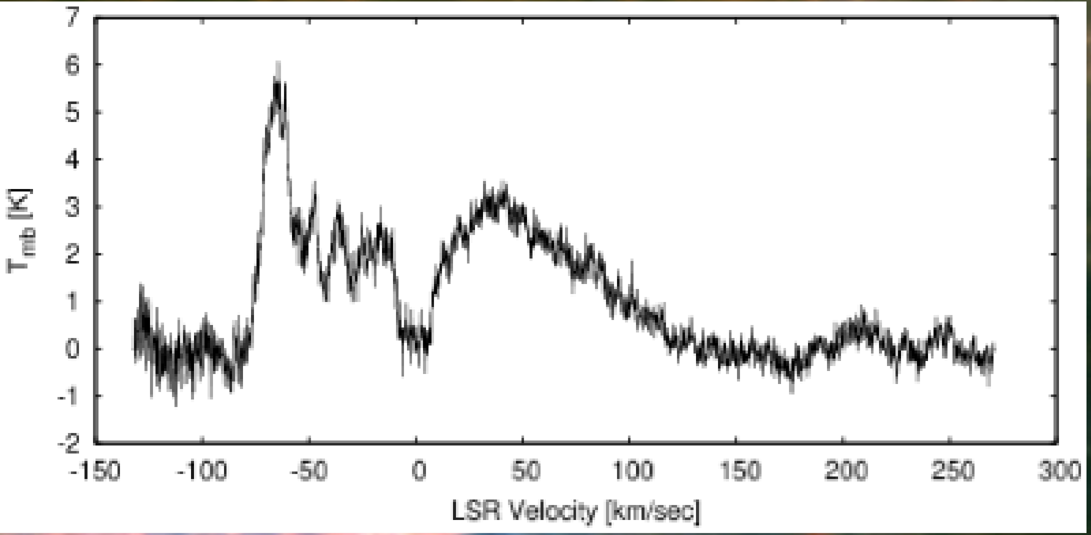
Outline

- Motivation
- MgB_2 material and thin films
- HEB mixer
- JJ mixer
- Future directions
- Summary

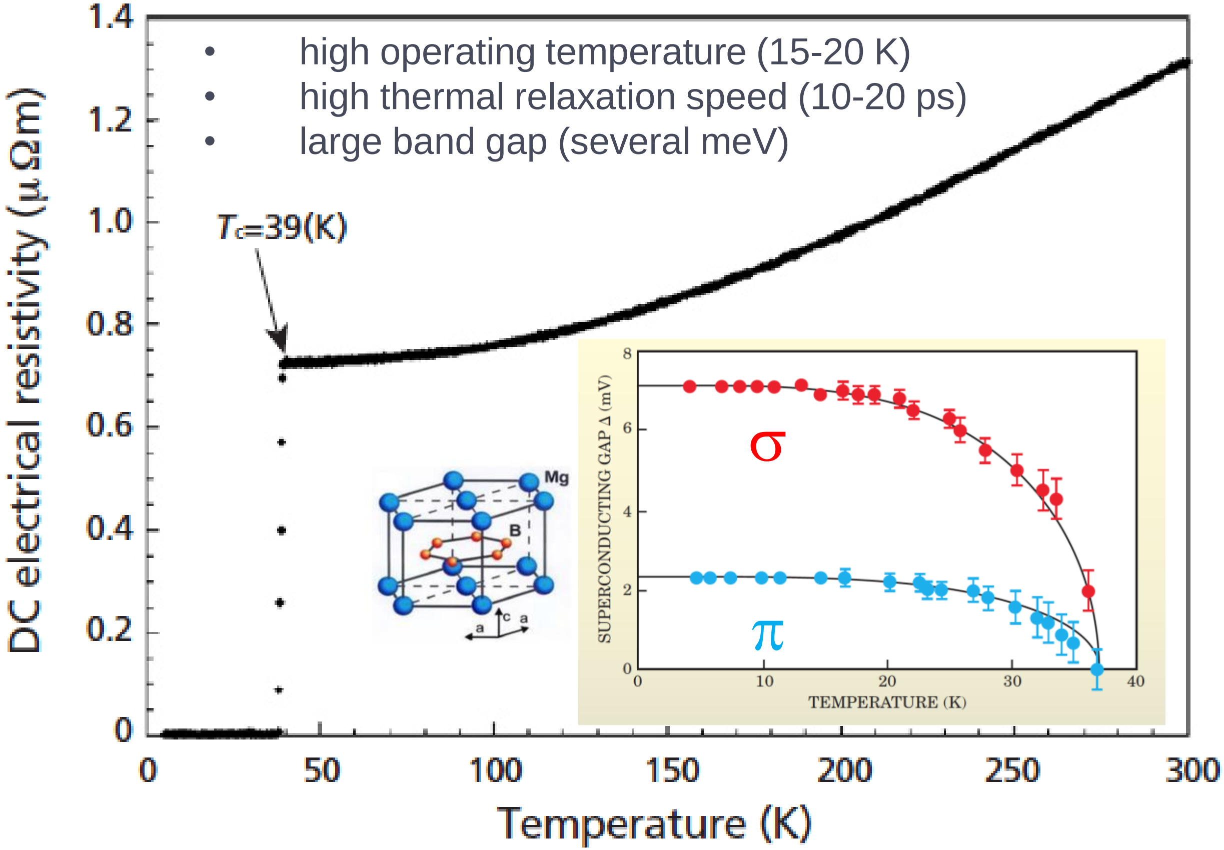
Motivation



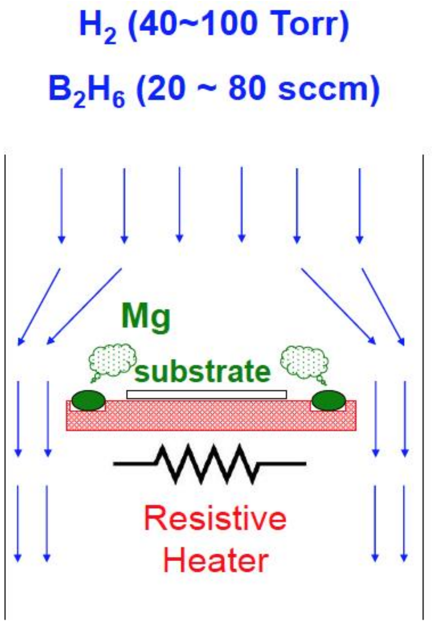
- Cryocooling in space to 20 K rather than to 4 K
- [HD] 2.70 THz, [OIII] 3.40 THz, [OI] 4.74 THz, [NIII] 5.85 THz
- IF bandwidth up to 8 GHz in order to capture emission from multiple molecular clouds along the line of sight

Superconductivity in MgB_2

- high operating temperature (15-20 K)
- high thermal relaxation speed (10-20 ps)
- large band gap (several meV)



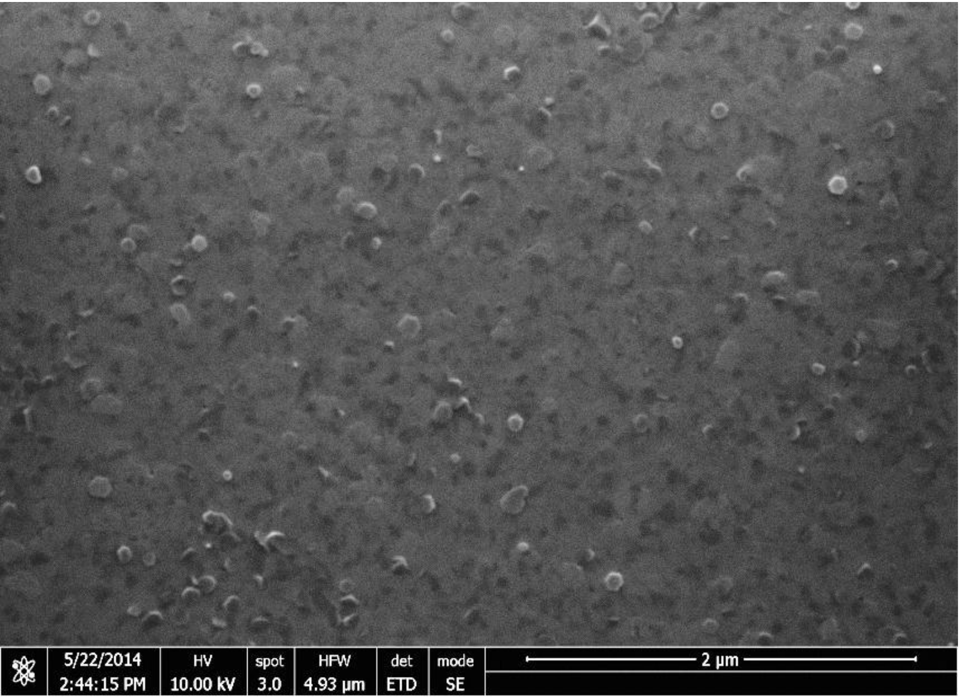
Hybrid Chemical-Physical Vapor Deposition (HPCVD)



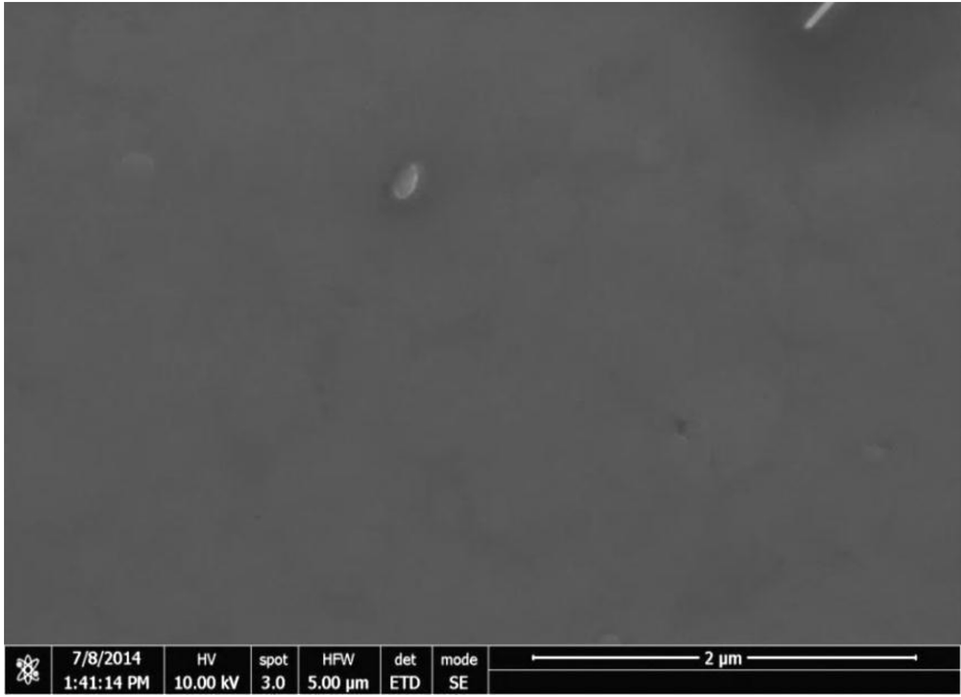
- the process yields very thin films (≈10 nm) with high T_C and low resistivity
- on 6H-SiC, MgB_2 films grow predominantly c-axis oriented

As-grown and ion-milled films

15 nm thick films

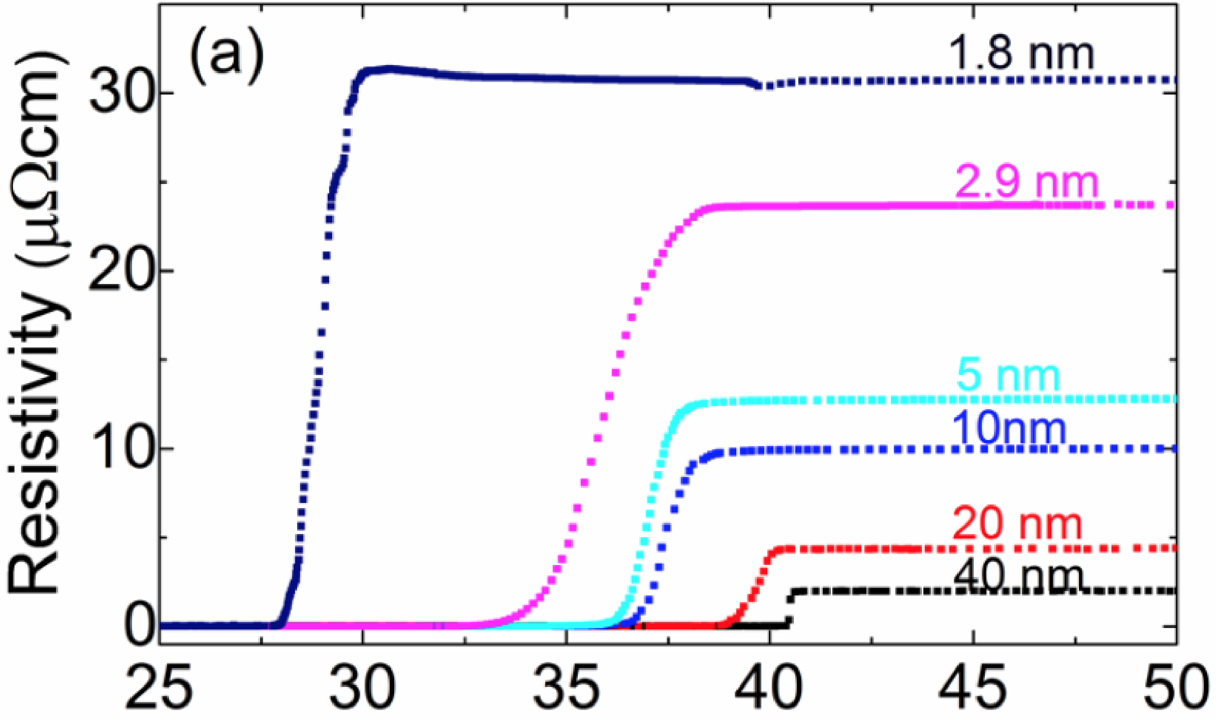


HPCVD alone



HPCVD+ion mill

Milled-down HPCVD films



N. Acharya et al., *APL Mater.* **4**, 086114 (2016)

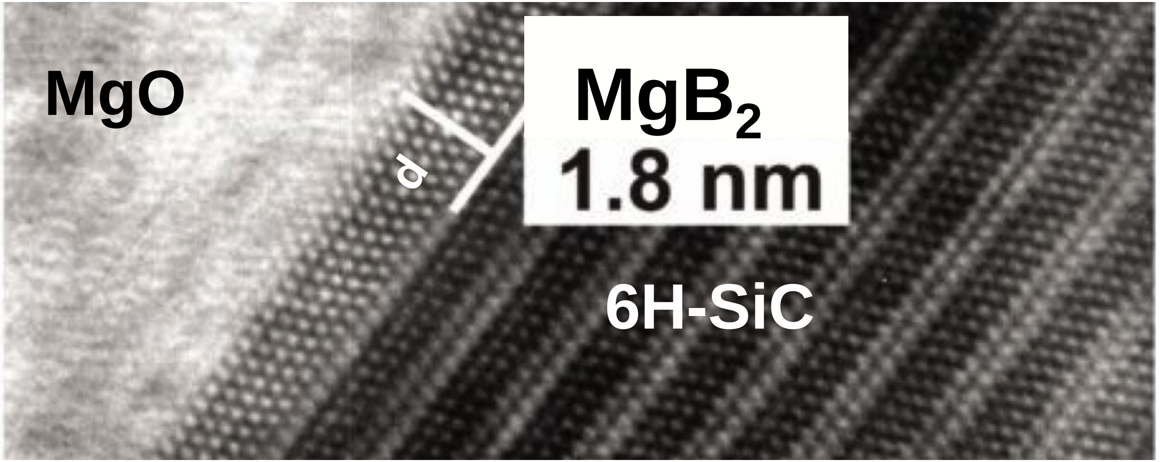
MgB_2 HEB Mixer

D. Cunnane et al., *IEEE Trans. Appl. Supercond*. **27**(4), 2300405 (2017)

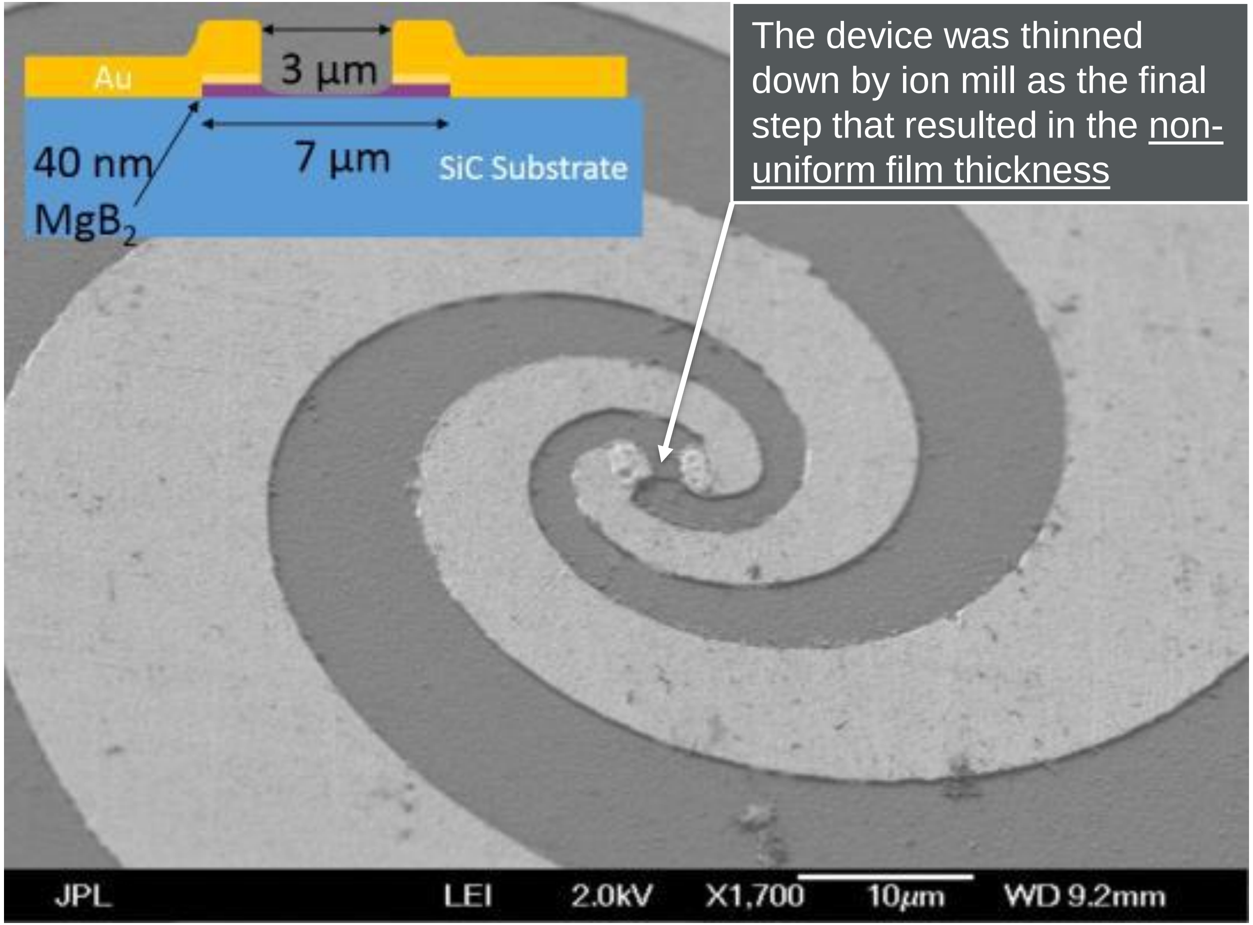
Fast escape of phonons from MgB_2 to SiC

Because of the high electron temperature (~ T_C), phonon escape ($\tau_{es} = 4d/v_s\alpha$) is the bottleneck for the energy relaxation in MgB_2 HEB

Material	MgB_2	NbN
v_s (km/s)	8-10	2.5

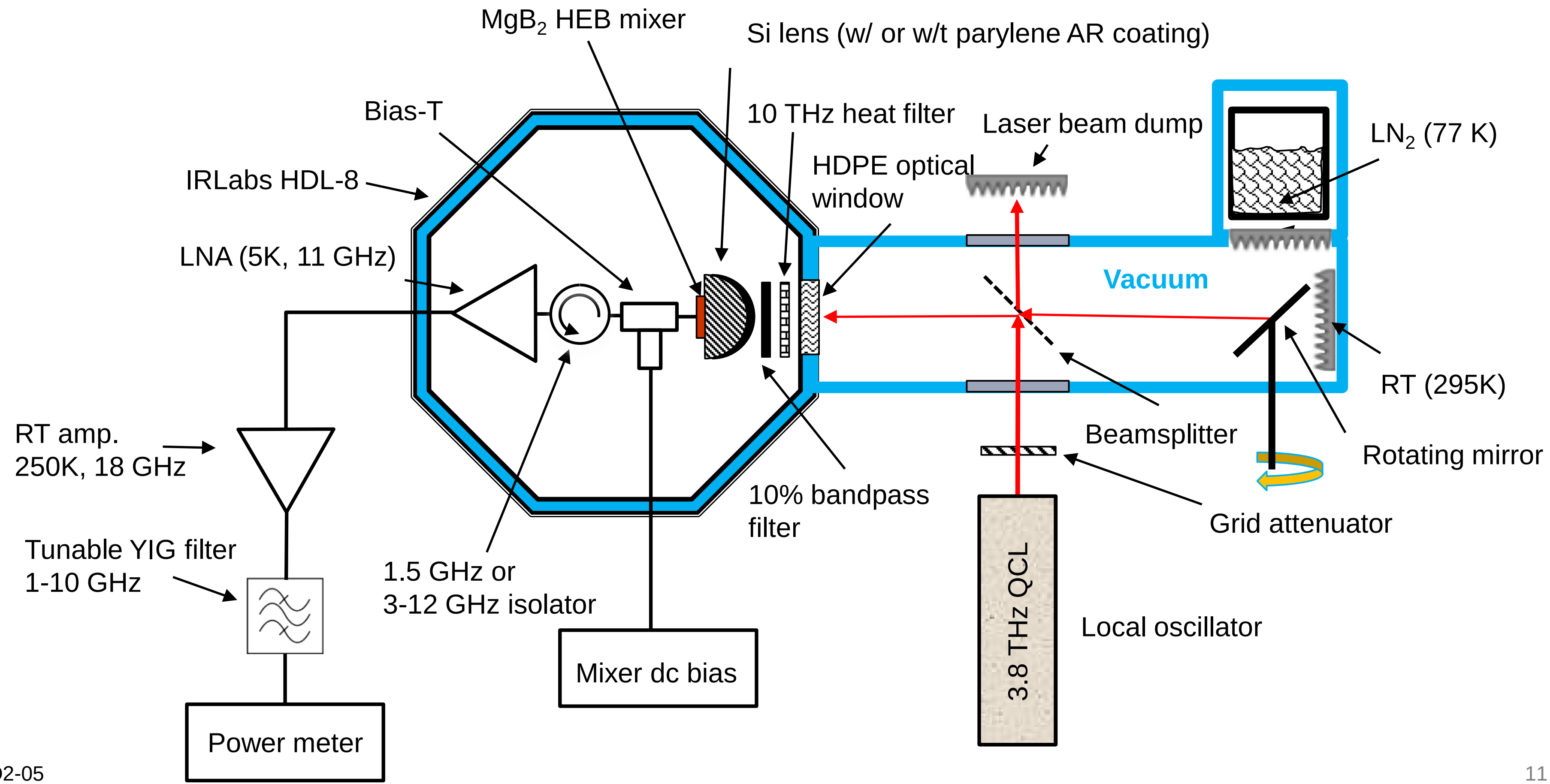


Antenna-coupled MgB_2 HEB

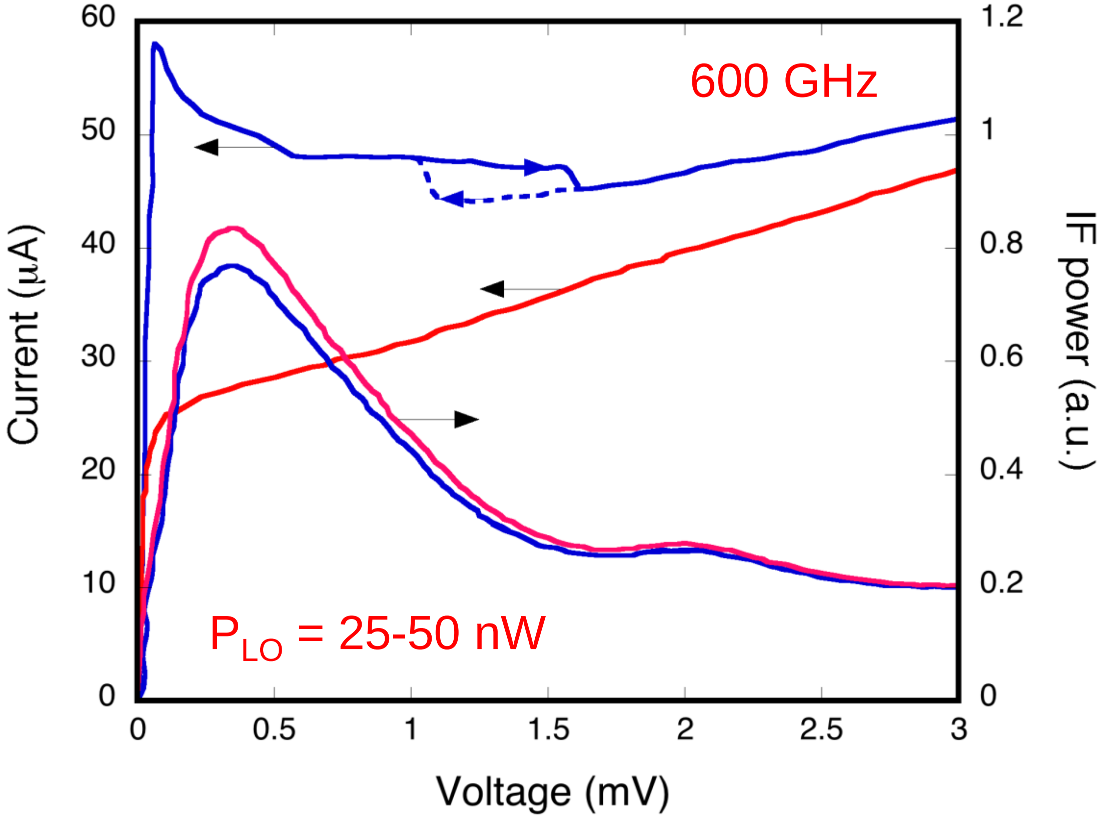


The device was thinned down by ion mill as the final step that resulted in the non-uniform film thickness

Mixer test setup

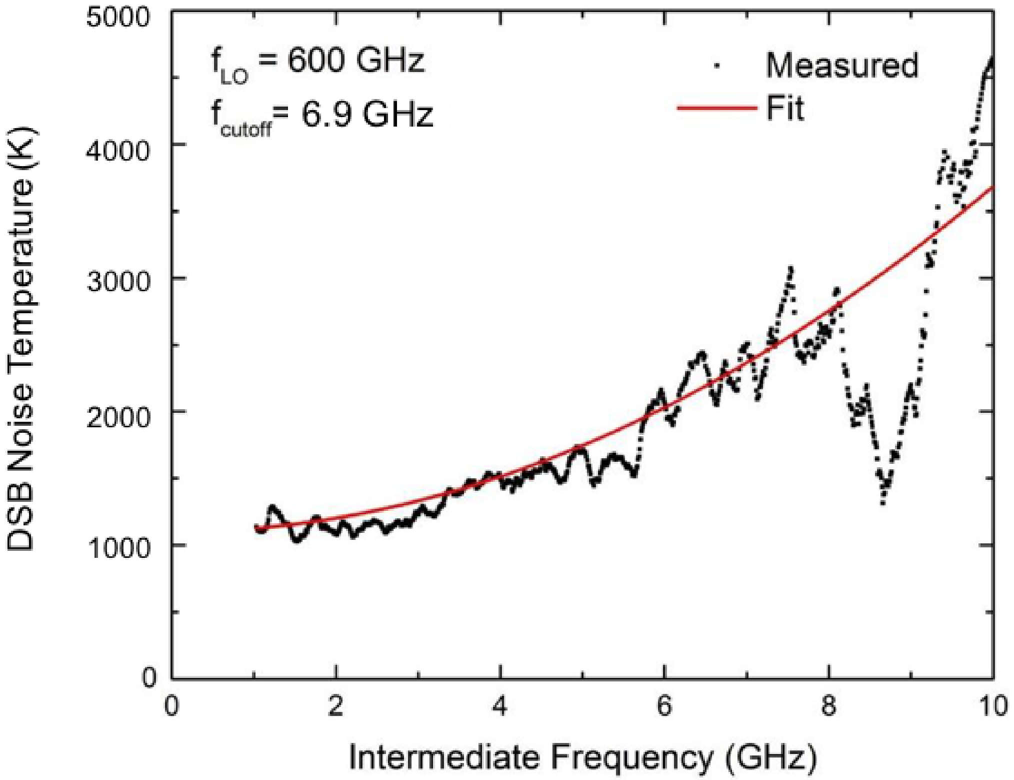


IV's and IF power



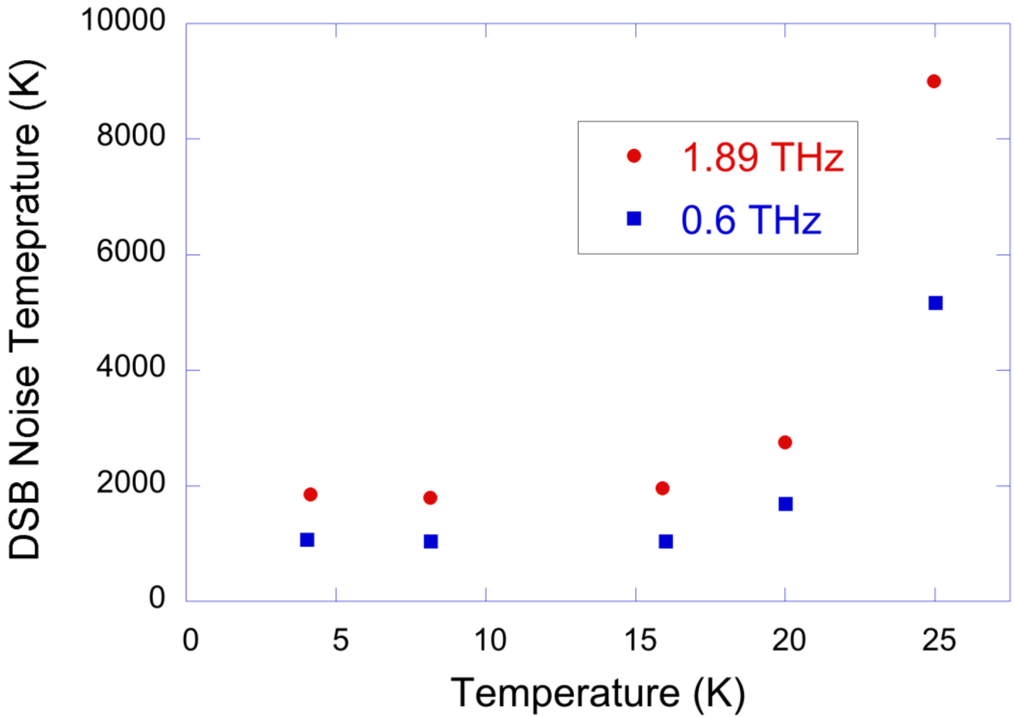
3 µm x 1 µm x 5 nm HEB device

Noise bandwidth



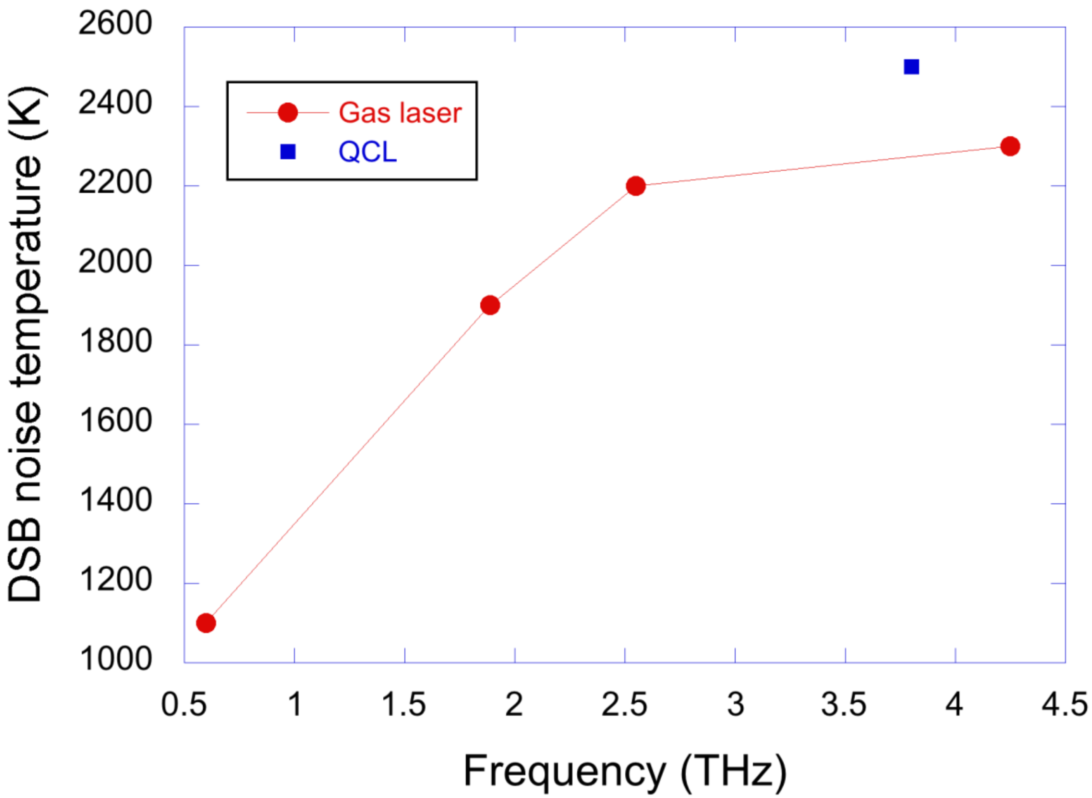
Corrected for beamsplitter and AR coating loss

Noise temperature vs bath temperature



Corrected for beamsplitter and AR coating loss

Summary of noise temperature data

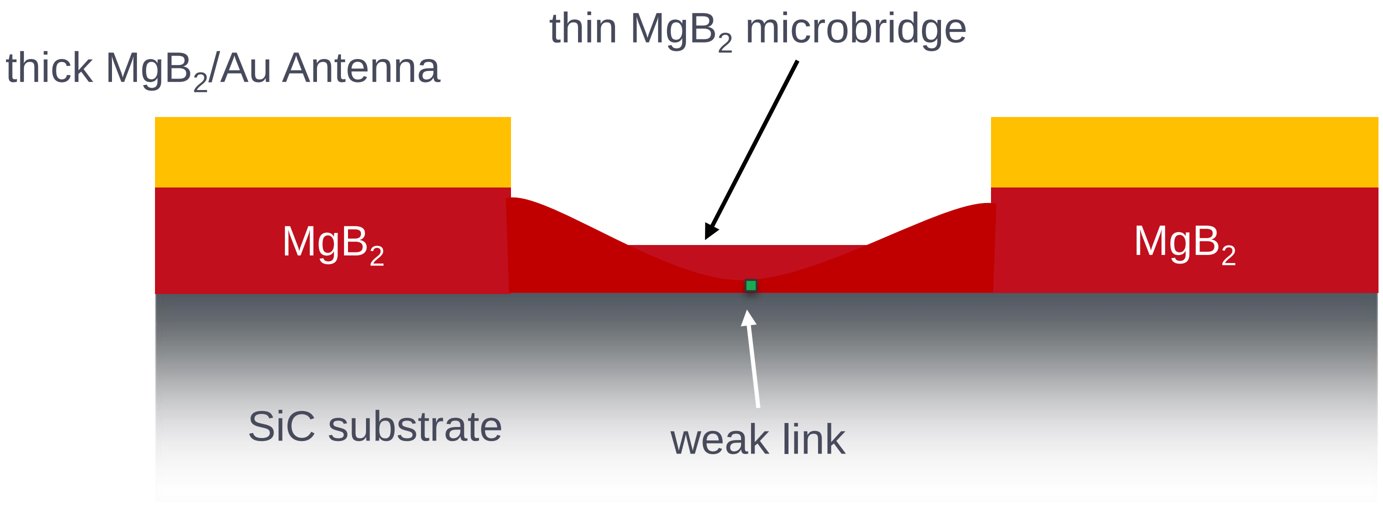


Corrected for beamsplitter and AR coating loss

Josephson Junction Mixer

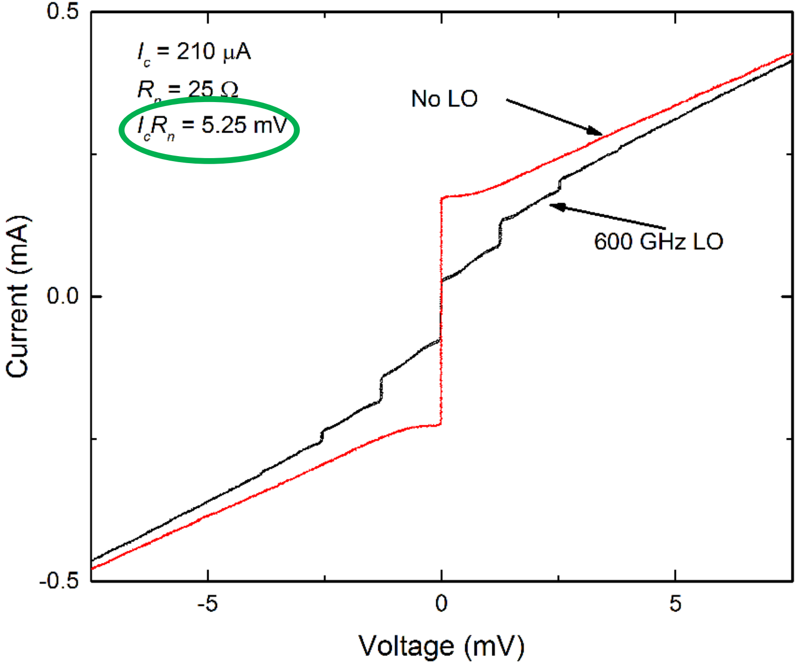
D. Cunnane et al., *Appl. Phys. Lett.* **109**, 112602 (2016)

In-plane Josephson junction

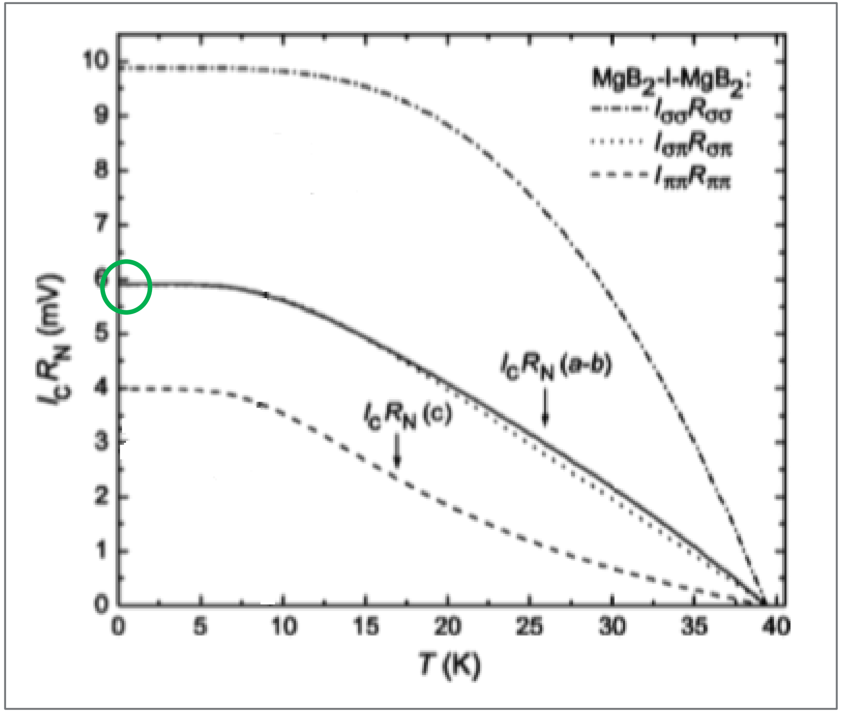


- in-plane (a-b) WL junction is due to the film overetching during the ion mill process
- similar technique using FIB was employed for fabrication of YBCO JJ Cybart et al., *NatNANO* **10**, 598 (2015)
- because of the strong c-axis orientation of the film, σ-gap contributes in Josephson tunneling

Josephson mixing at 600 GHz

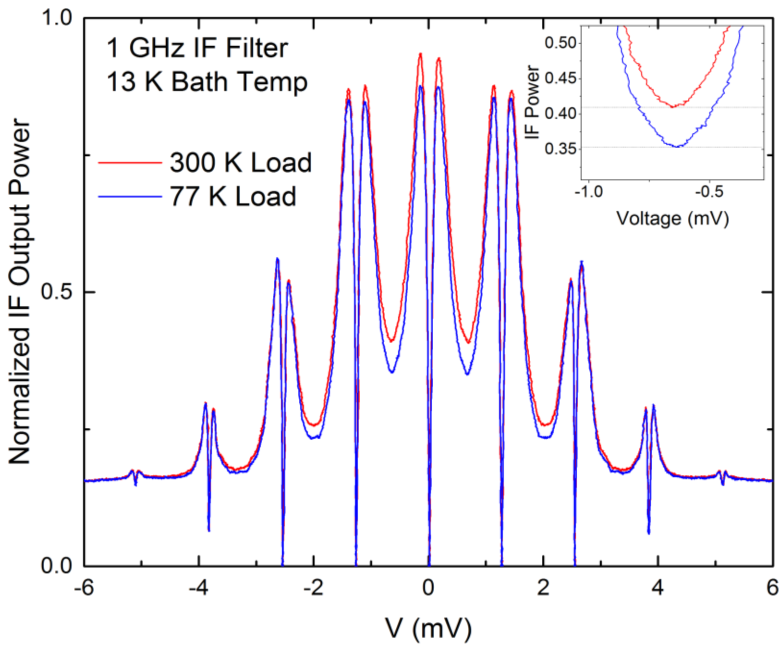


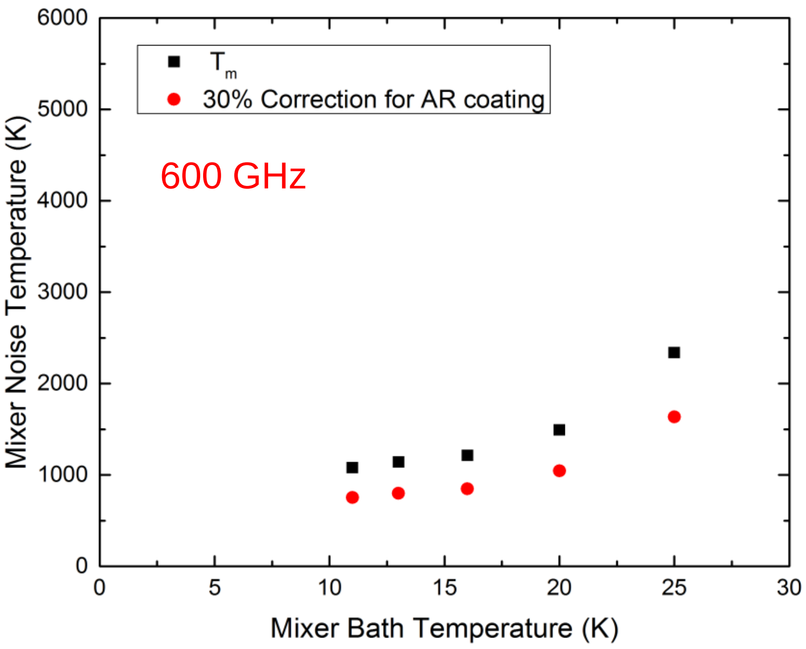
Shapiro steps at V = hν/2e



A. Brinkman et al., *Phys. Rev*. B **65**, 180517R (2002)

JJ mixer noise temperature





- NT ≈ 1,500 K has been measured at 1.9 THz (after correction for optical loss)
- focused development of this technology will likely improve NT

Future directions

- **Uniform HEB devices of submicron size**

❖ films on large (at least 3”) wafers to allow for projection photolithography

❖ smoother films (δ_{rms} < 1 nm) similar to those produced by MBE technique

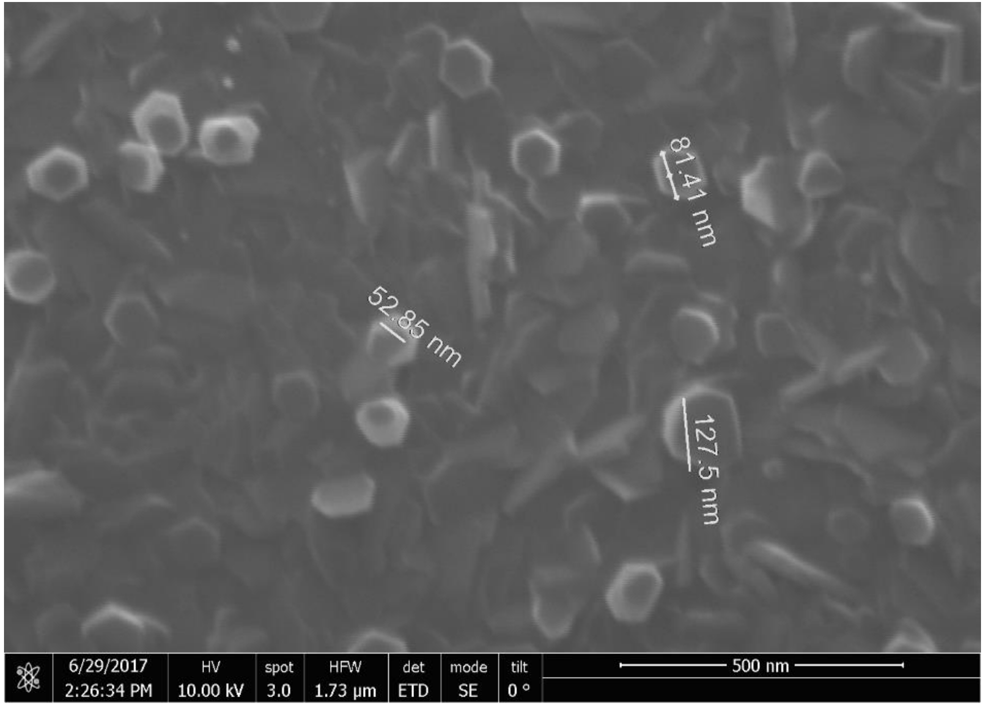
- **Waveguide coupled mixer**

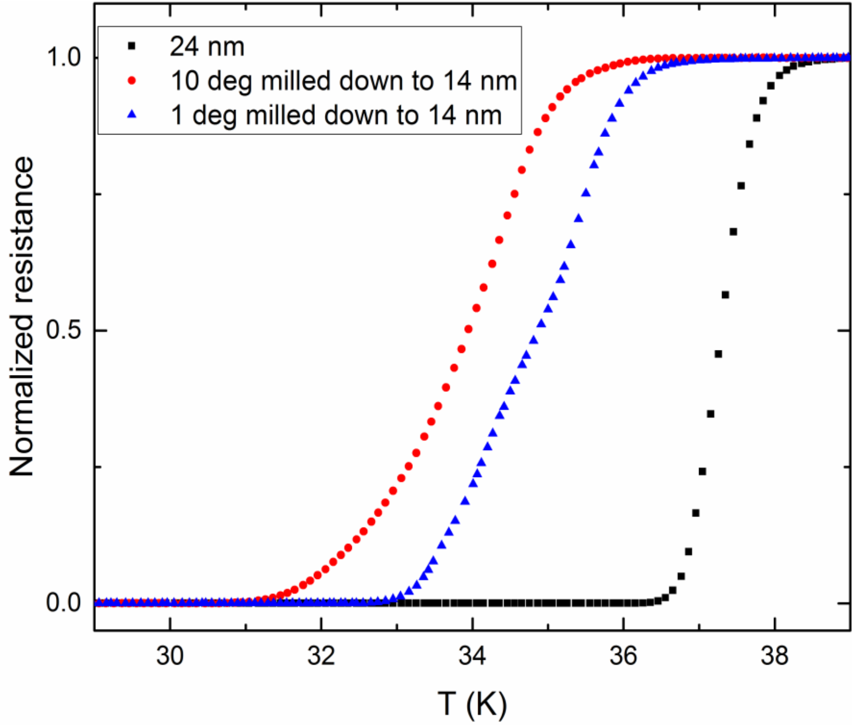
❖ films on Si membranes

- **Wafer-scale reproducible Josephson junctions**

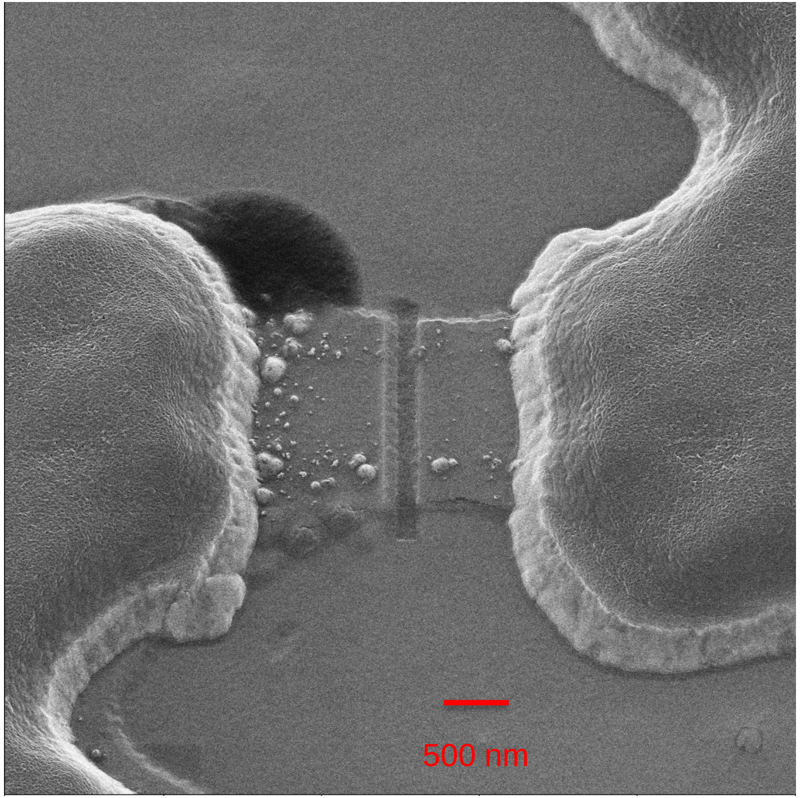
❖ Josephson junctions using FIB direct milling

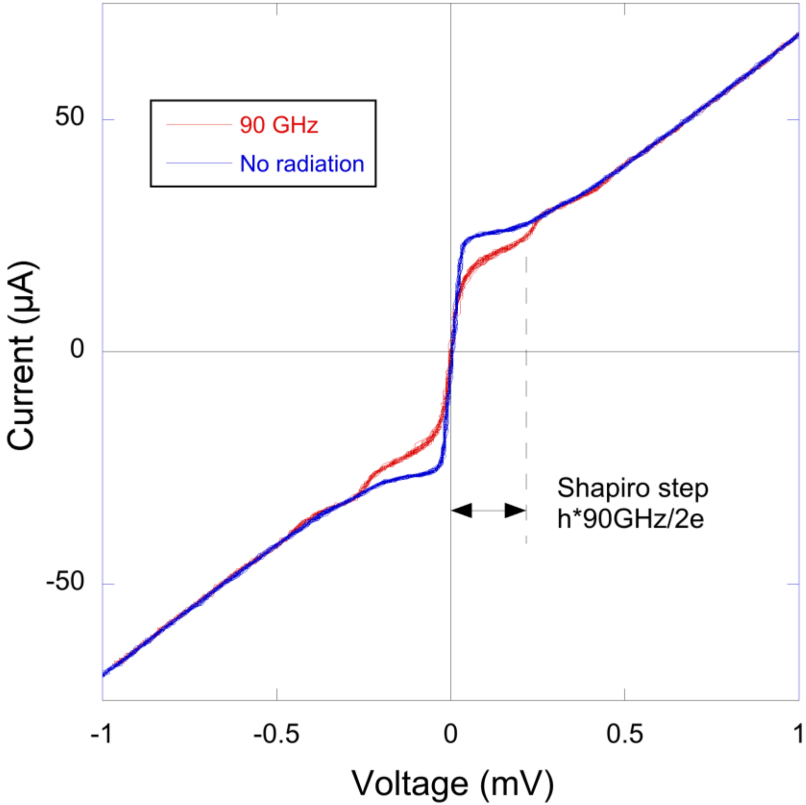
MgB_2 films on Si





In-plane JJ using a neon FIB





Summary

- The HPCVD technique in combination with ion milling yields high quality ultrathin MgB_2 films suitable for development of THz heterodyne detectors operating up to 15-20 K

- High thermal relaxation rate in MgB_2 films makes possible an IF bandwidth in HEB ~ 10 GHz

- Low-noise MgB_2 HEB mixers can work up to 5 THz

- Josephson mixing is promising for heterodyne detectors up to 2 THz

- More work is needed to improve the film/device quality

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