Complex conductivity of strongly disordered thin MoC superconducting films

Martin Baránek[1], Pavol Neilinger[1,2], Daniel Manca[1], Miroslav Grajcar[1,2]

[1] Department of Experimental Physics, Comenius University, Mlynská dolina F1, 84248, Bratislava, Slovakia
[2] Institute of Physics, Slovak Academy of Sciences, Dúbravská cesta 9, 84511, Bratislava, Slovakia

This work was supported by the Slovak Research and Development Agency under the contract APVV-16-0372, APVV-18-0358 and by the QuantERA grant SiUCs, by SAS-MTVS

Superconductivity

- Disordered superconductors
  - High sheet resistance → high kinetic inductance L_k
  - Suppressed T_c
  - Deviation from BCS theory
- Complex conductivity for Dynes superconductors [1] with Dynes parameter Γ

$$\sigma = \sigma_1 - i\sigma_2$$

$$\frac{\sigma_1}{\sigma_n} = \frac{2}{\hbar\omega}\int_{\Delta}^{\infty}[f(E) - f(E+\hbar\omega)]g_1(E)dE + \frac{1}{\hbar\omega}\int_{\Delta-\hbar\omega}^{-\Delta}[1-2f(E+\hbar\omega)]g_1(E)\mathrm{d}E$$

$$\frac{\sigma_2}{\sigma_n} = \frac{2}{\hbar\omega}\int_{max(\Delta-\hbar\omega,-\Delta)}^{\Delta}[f(E) - f(E+\hbar\omega)]g_2(E)\mathrm{d}E$$

$$g_1 = ig_2 = \left(1 + \frac{\Delta^2}{E(E+\hbar\omega)}\right)N_S(E)N_S(E+\hbar\omega)$$

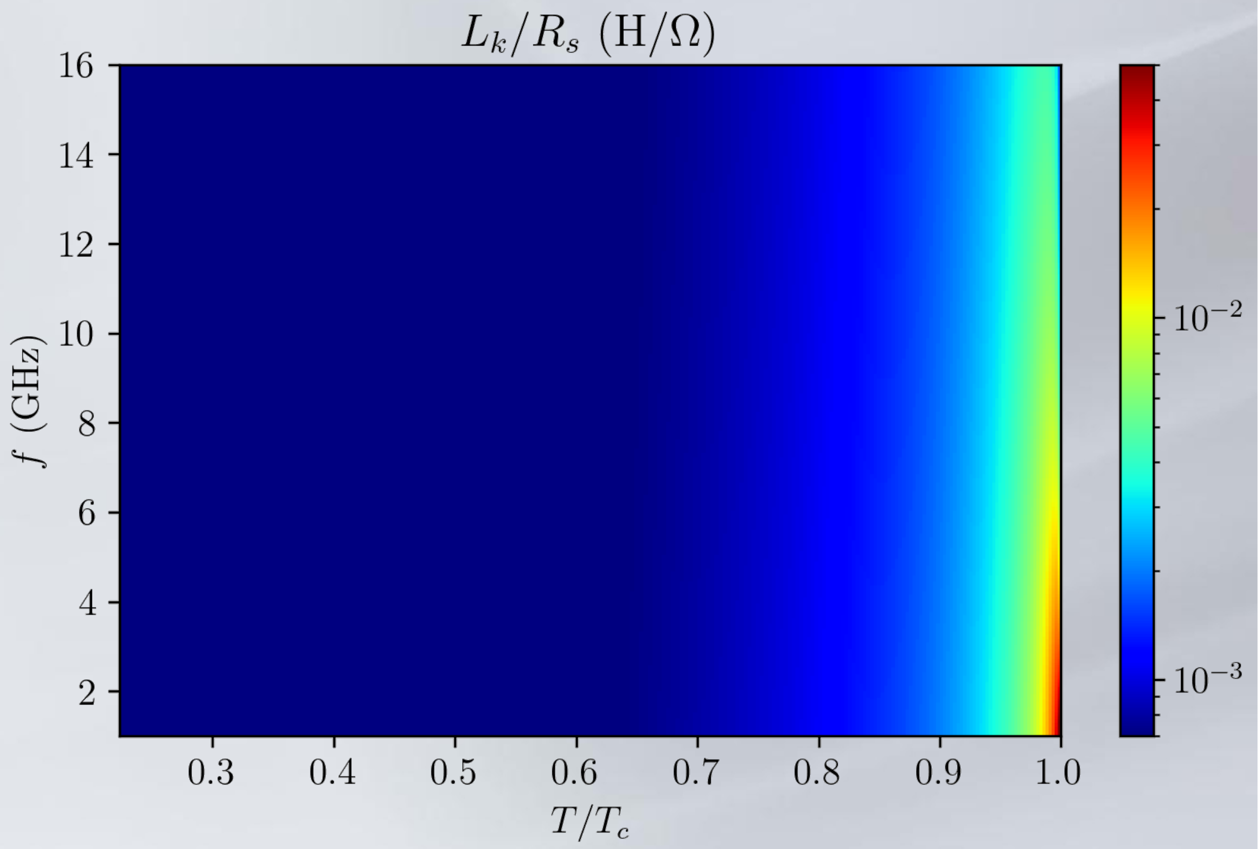
1. M. Žemlička et. Al., Finite quasiparticle lifetime in disordered superconductors, 2015, Phys. Rev. B 92(22) 224506

Kinetic inductance

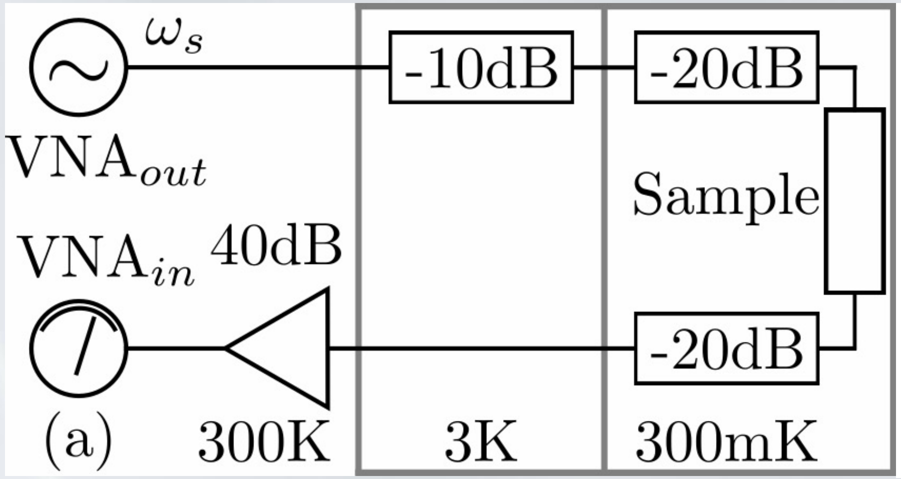
- Kinetic inductance L_k (σ) dependent on σ(T, Tc (Δ_0), Γ/Δ_0, ω)

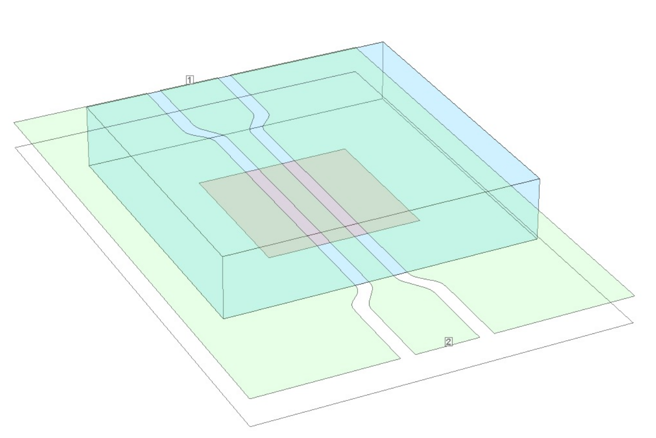
$$L_k(\omega, T, T_c, \Gamma) = \frac{\sigma_2}{\omega(\sigma_1^2 + \sigma_2^2))}$$

- Proportional to R_s



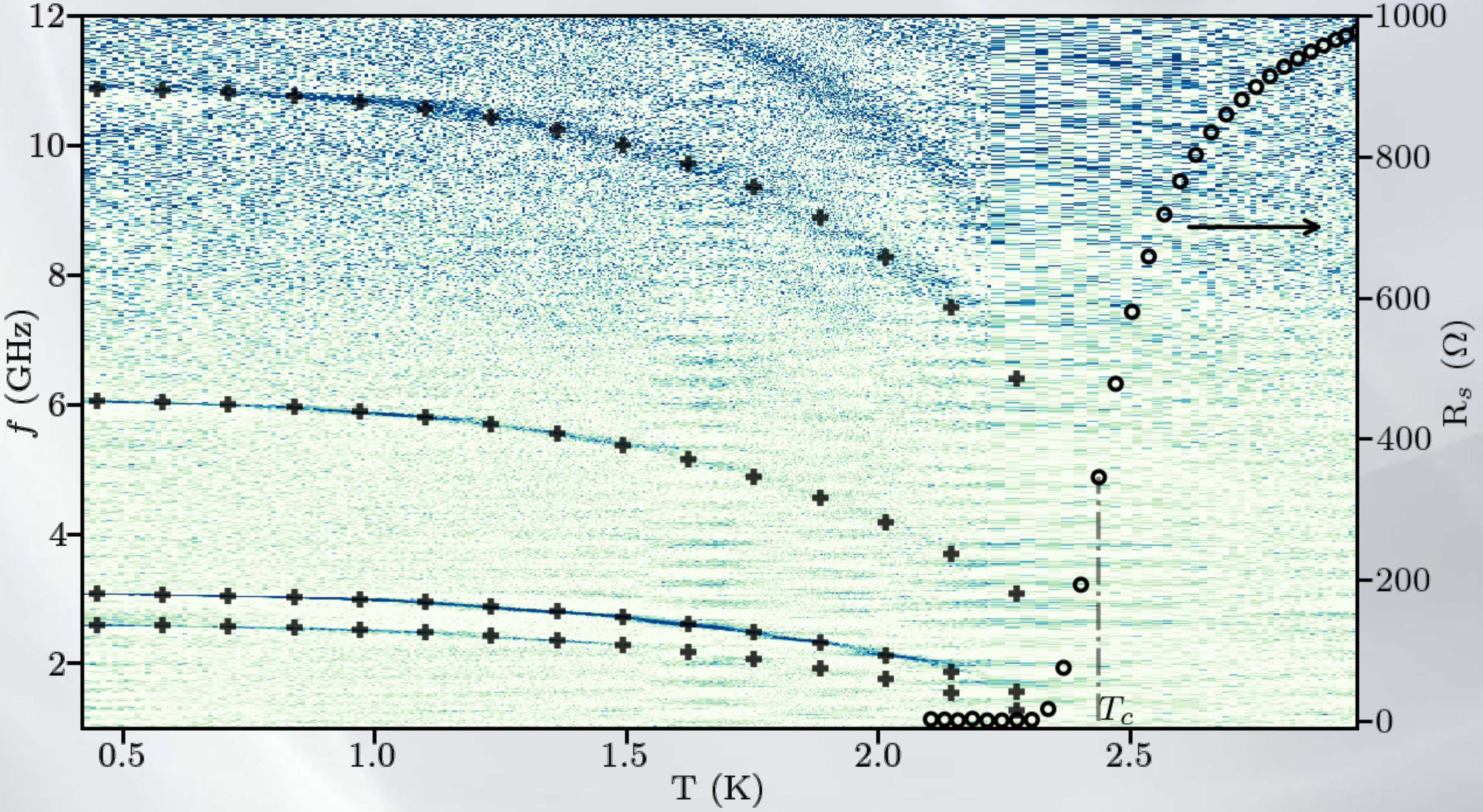
Experiment





- Flip-chip transmission line spectroscopy
- Vector Network Analyzer – 1-12 GHz frequency range
- Temperatures down to ~ 360mK
- Samples – thin MoC films on sapphire substrate, varied disorder

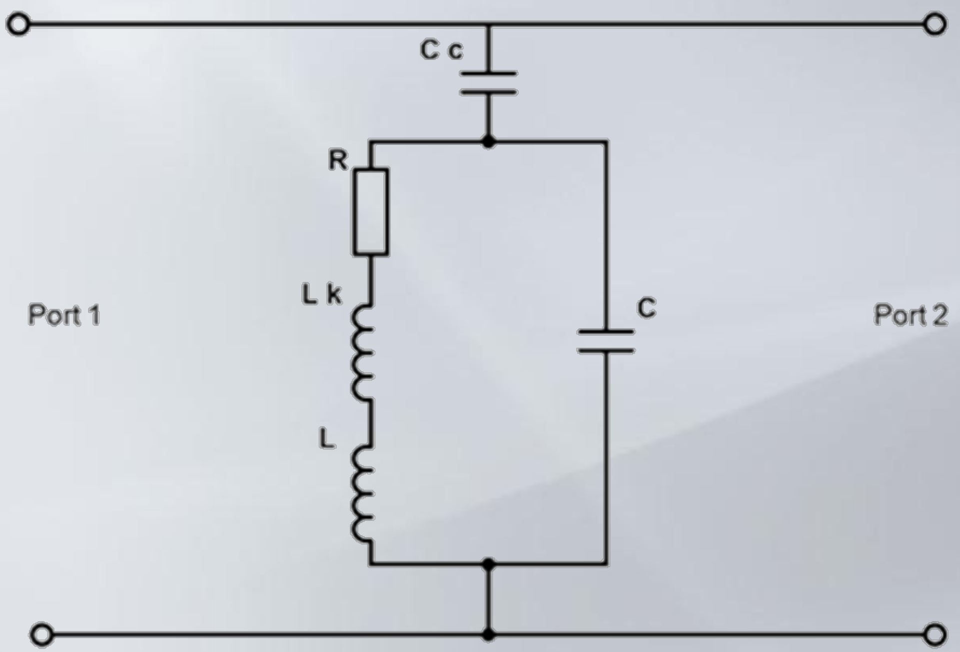
Transmission spectrum R_s = 970Ω



- Resonances in transmission spectra, up to T_c

Lumped LC resonance circuit model

$$\omega_n^r(T) = \frac{1}{\sqrt{(L_k + L_n)C_n}} = \frac{\omega_n^{(0)}}{\sqrt{1 + g_n L_k(\omega, T, \Delta, \Gamma)}}$$



- Geometry-given resonance frequency: $\omega_n^{(0)}$

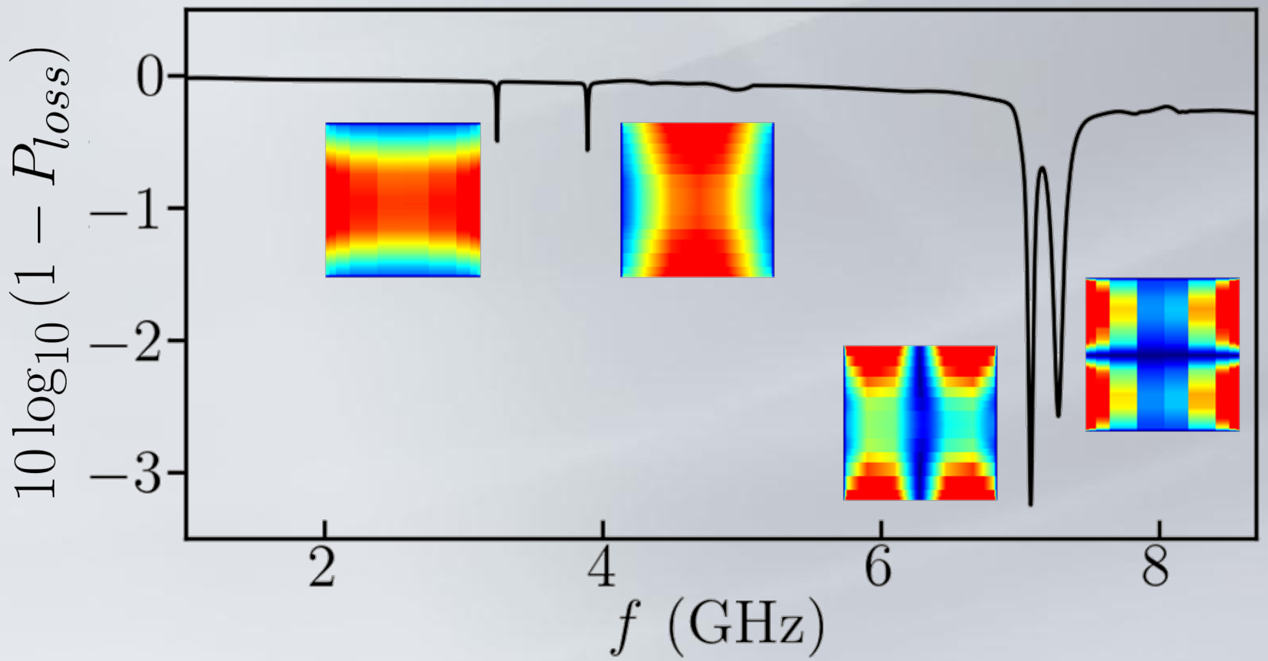
- Temperature dependence - kinetic inductance dominated

Results

- Resulting fit parameters T_c^{spec}, Γ^{spec}/Δ_0
  - Correspond with Scanning tunneling spectroscopy
  - Correspond with DC R-T measurements

Sample	Rs [Ω]	T_c^{DC} [K]	T_c^{spec} [K]	Γ^{STS}/Δ_0	Γ^{spec}/Δ_0
B	212	7.04	7.02	0.03	0
C	565	4.85	5.11	0.2	0.2
D	974	2.44	2.52	0.44	0.5

- Numerical simulations
  - Qualitative agreement
  - Current density – eigenmodes of MoC film



M. Baránek et. Al., Kinetic planar resonators from strongly disordered ultra-thin MoC superconducting films investigated by transmission line spectroscopy, 2021, arXiv:2102.13483