Terahertz characterization of superconducting MoRe films

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Introduction

Due to the lack of works devoted to such perspective in superconducting electronic material as $Mo_{0.6}Re_{0.4}$ we set our goal to characterize and analyze the behavior of thin films made of this alloy at frequencies 0.15 - 2.4 THz (5 cm^{-1} – 80 cm^{-1}) and in the temperature interval 5 K – 300 K. Spectra of complex permittivity, conductivity, and surface impedance of the films are obtained experimentally. For all films, quantitative temperature dependences of the superconducting energy gap, penetration depth, superconducting condensate plasma frequency, and normalized superfluid density are deduced. It is shown that the reduction of film thickness leads to a strong decrease of the critical temperature and energy gap.

Methods

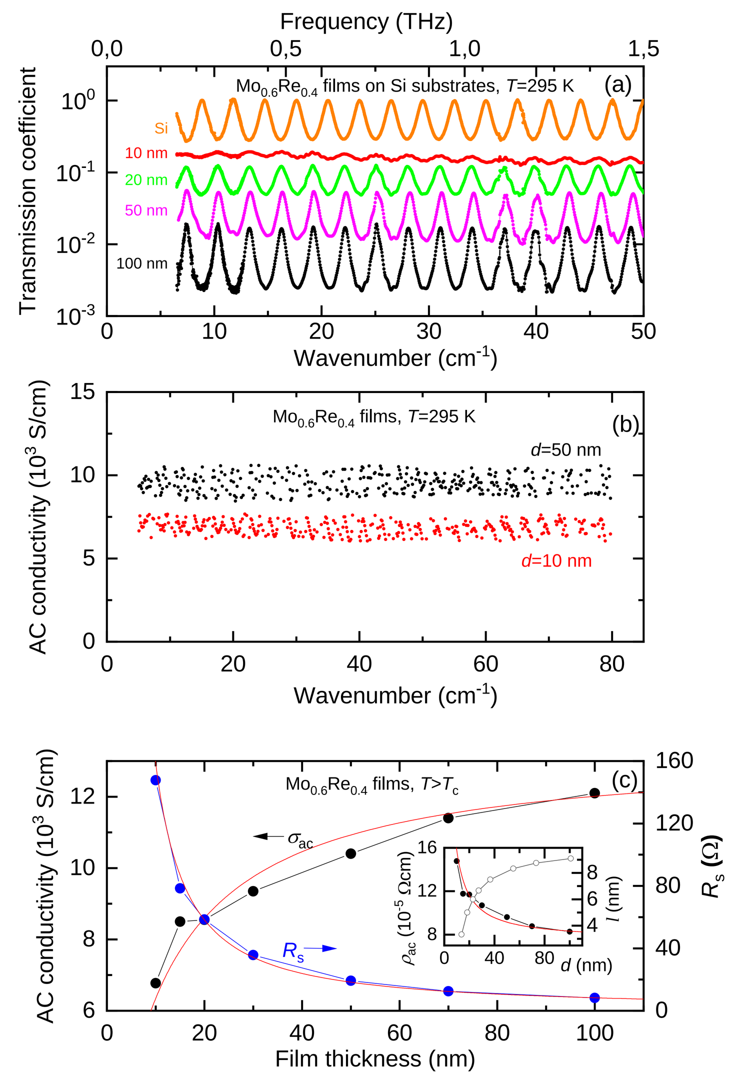
Films are prepared by magnetron sputtering technique on silicon substrates

Measurements:

- 4 point probe resistivity measurements
- Time-domain THz spectroscopy

Results

Normal state



Impedance matching of the "silicon-air" interface by thin $(d < \delta)$ conducting $Mo_{0.6}Re_{0.4}$ films

Dispersionless conductivity spectra in the normal state -> metal-type response in the limit $\nu \ll \gamma$ of Drude conductivity model

Fit with equations[1] for granular films with charge carriers scattered by film surface and grain boundaries

$$\rho(d) = \rho_0\left(1 + A\frac{l_0}{d}\right)$$

$A \sim 1,\quad \rho_0 = 75\,\mu\Omega\cdot cm,\quad l_0 = 10\,nm,$

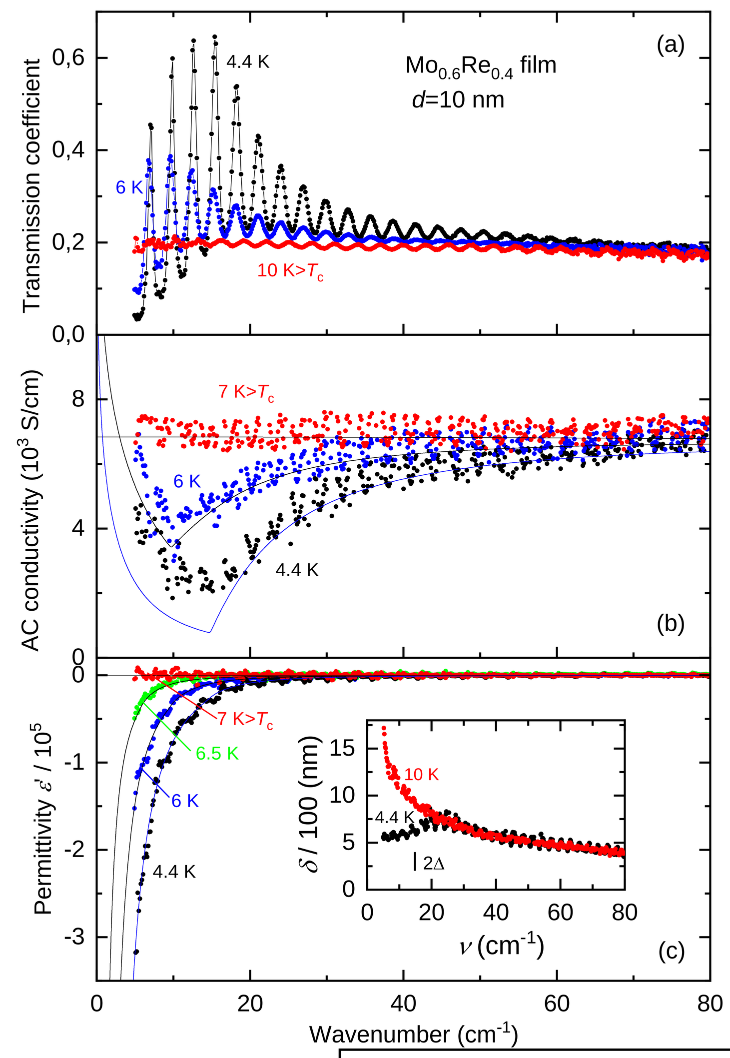
$v_F = 2.3\cdot 10^7\ cm/s$ (ref. 7)

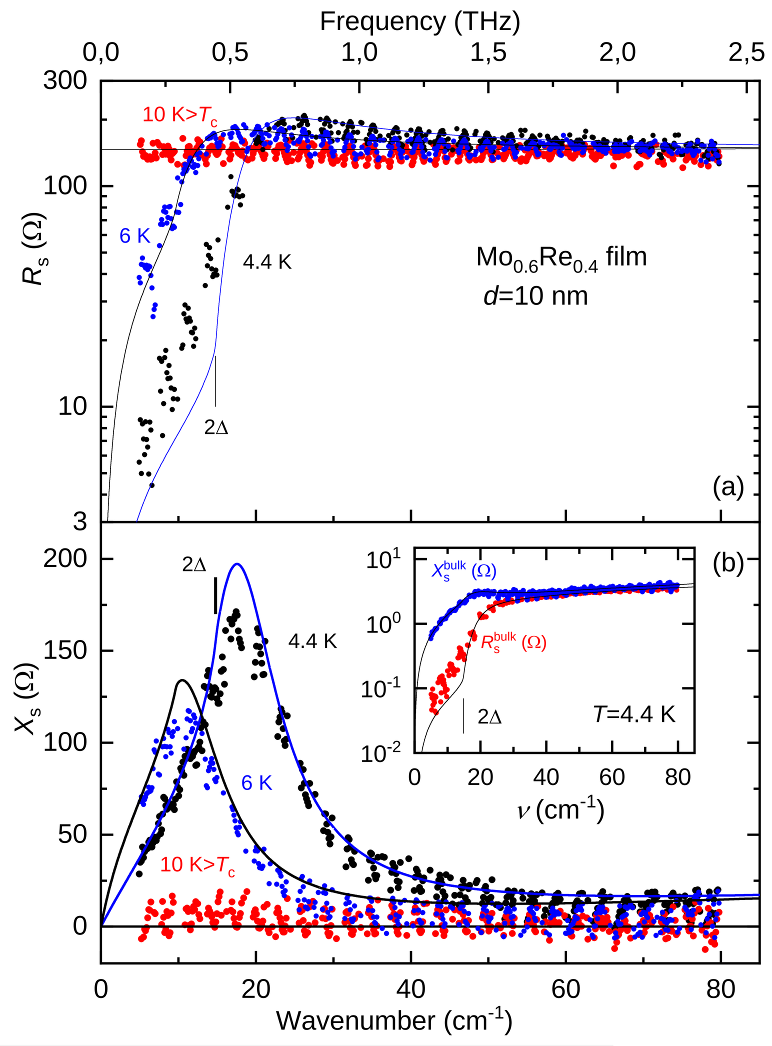
$$\gamma = \frac{v_F}{2\pi l_0} = 120\ cm^{-1}$$

Superconducting state

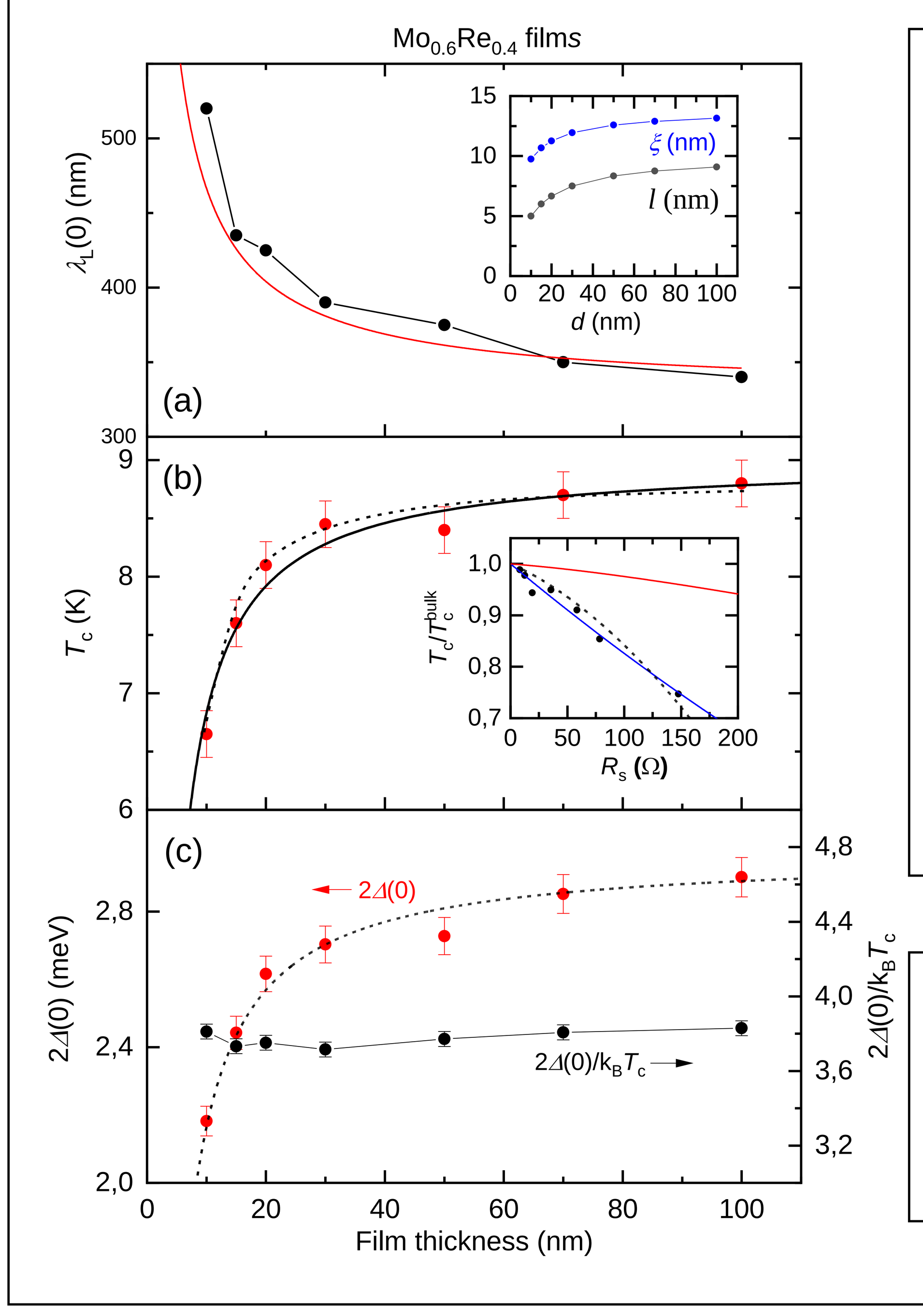
One-band contribution in contrast to reported[2] two band structure

Fits with BCS expressions from ref. 8





$$k_F = 1.4\cdot 10^8\frac{1}{cm},\ \lambda_F \sim 0.1\ nm,\ l \sim 1\ nm,\ \xi_0 \sim 30\ nm$$



Disorder

Maekawa and Fukuyama[3]

$$\ln\left(\frac{T_C}{T_C^{bulk}}\right) = -\frac{1}{2}\frac{(g_1 - 3g')N(0)e^2R_{sh}}{2\pi^2\hbar}\left[\ln\left(5.5\cdot\frac{\xi_0}{l}\cdot\frac{T_C^{bulk}}{T_C}\right)\right]^2 - \frac{1}{3}\frac{(g_1 + g')N(0)e^2R_{sh}}{2\pi^2\hbar}\left[\ln\left(5.5\cdot\frac{\xi_0}{l}\cdot\frac{T_C^{bulk}}{T_C}\right)\right]^3$$

Finkel'shtein[5]

$$\frac{T_C}{T_C^{bulk}} = e^{-\frac{1}{\gamma}}\left[\frac{1+\frac{\sqrt{t/2}}{\gamma - t/4}}{1-\frac{\sqrt{t/2}}{\gamma - t/4}}\right]^{1/\sqrt{2t}}$$

$$t = \frac{e^2}{2\pi^2\hbar}R_{sh}$$

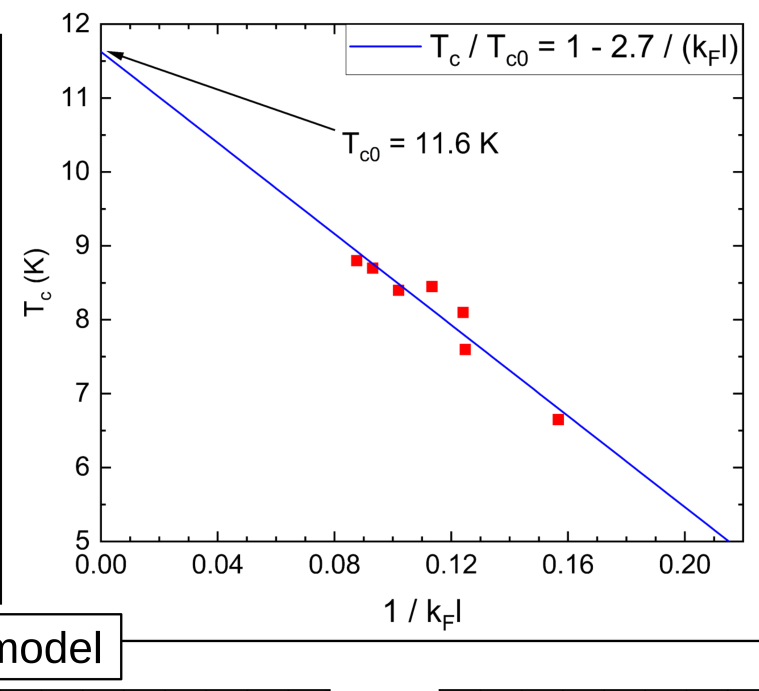
$$\gamma = 1/\log\left(T_C^{bulk}\tau\right)$$

Antonenko and Skvortsov[4]

2D diffusion + 3D ballistics

$$\frac{T_c}{T_{c0}} = 1 - \frac{\alpha}{k_F l}$$

$$\alpha \sim 1$$



Surface contribution

$$T_C(d) = T_C^{bulk}\left[1 - \frac{d_C}{d}\right]$$

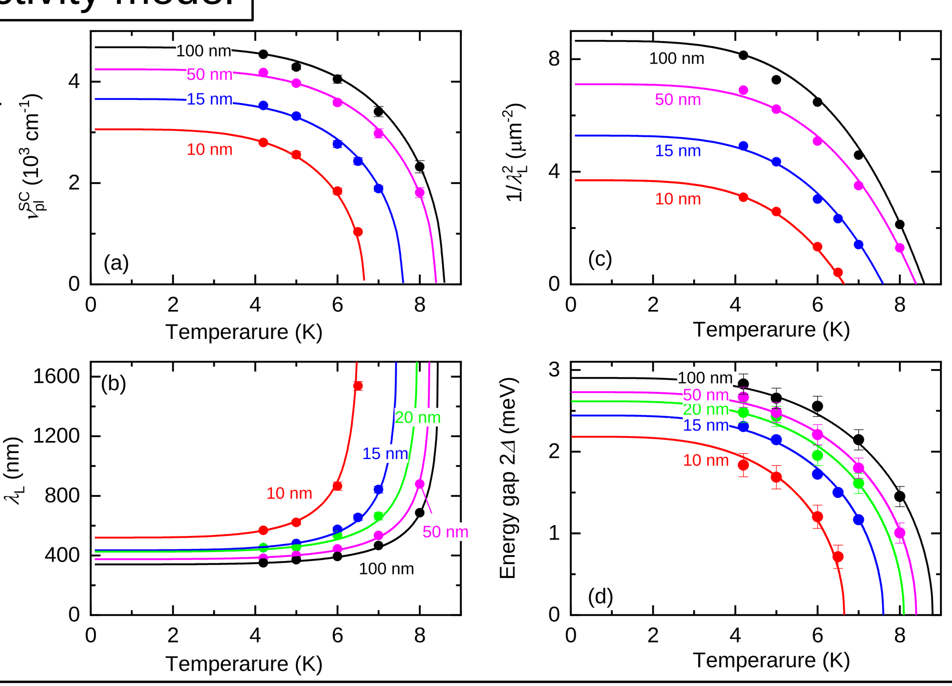
Simonin[6]

2-fluid superconductivity model

$$\nu_{pl}^{SC}(T) = \nu_{pl}^{SC}(0)\sqrt{1-\left(\frac{T}{T_C}\right)^4}$$

$$\lambda_L(T) = \frac{\lambda_L(0)}{\sqrt{1-\left(\frac{T}{T_C}\right)^4}}$$

$$\frac{1}{\lambda_L^2} \sim 1 - \left(\frac{T}{T_C}\right)^4$$



Conclusion

- Conducted first systematic studies of terahertz electrodynamic properties of $Mo_{0.6}Re_{0.4}$ films of thicknesses ranging from 10 nm to 100 nm
- The spectra of conductivity and permittivity are described within BCS single-band approach
- The strong decrease of the T_C and 2Δ in thinner films is associated with the suppression of the superconducting order parameter due to the contribution to the free energy of surface states

Acknowledgement

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