Peculiarities of the microwave conductivity of superconducting single crystals with different doping levels

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Content

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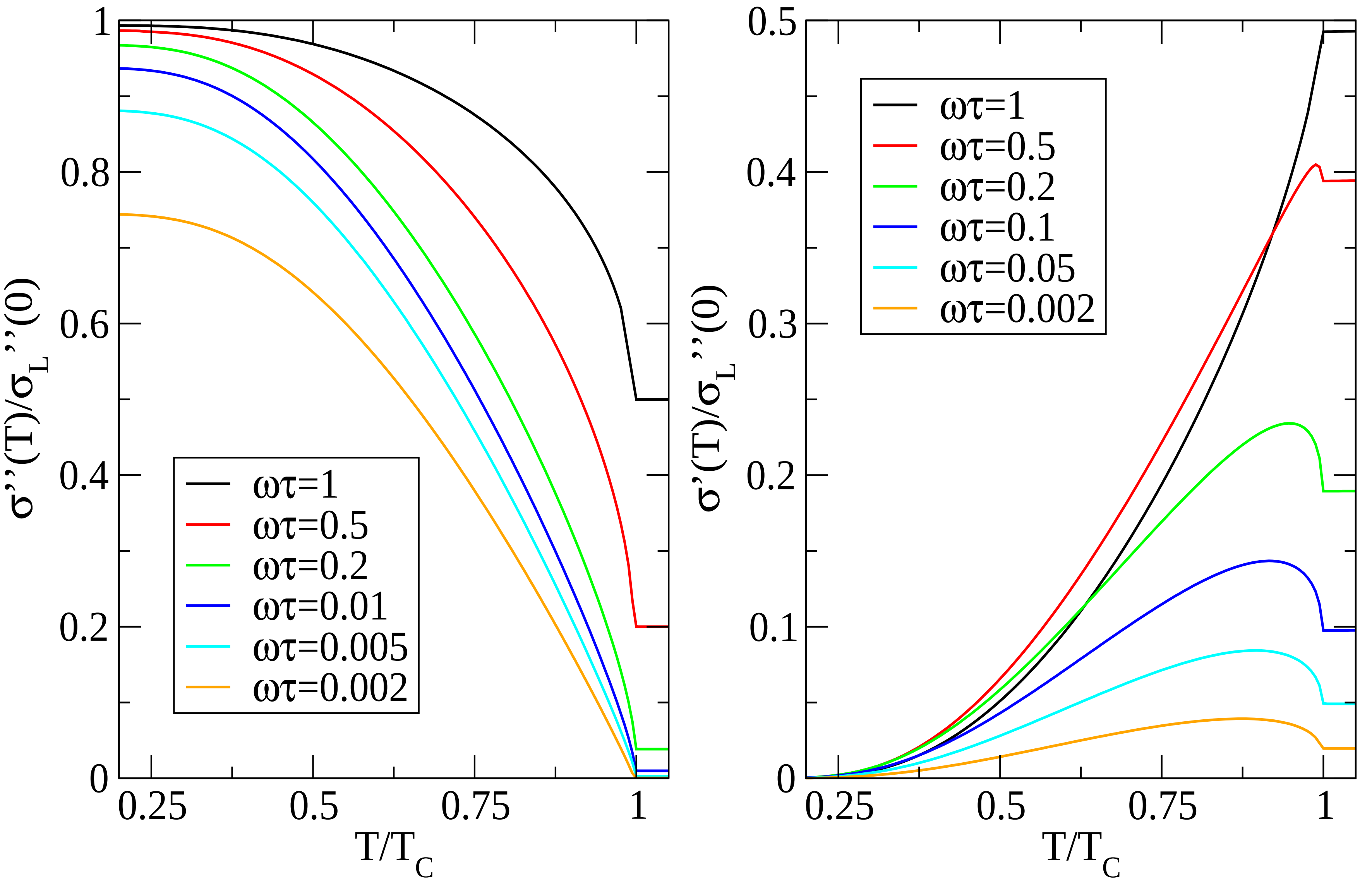
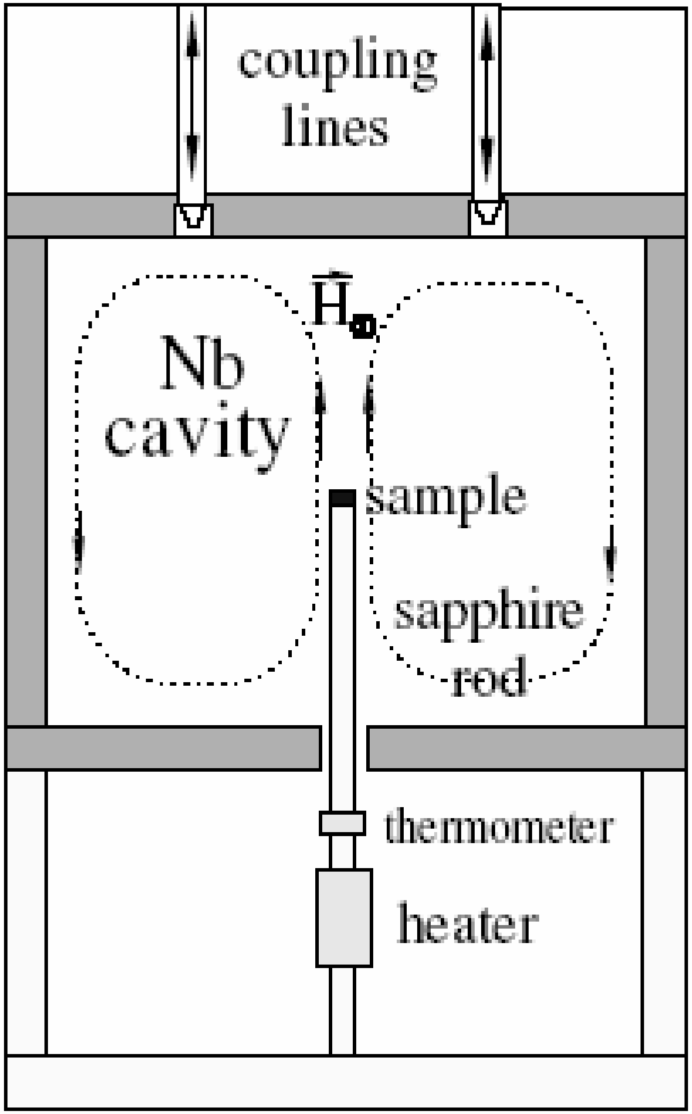
III. **Observation of a transition from BCS-type to HTSC-like superconductivity in $Ba_{1-x}K_xBiO_3$ crystals with different potassium content**

IV. **Evolution of the temperature dependences of complex conductivity of V_3Si_{1-x} single crystals with different silicon content: Evidence for two-gap superconductivity**



σ''(T)/σ_L''(0)
T/T_C
0.25
0.5
0.75
1
0
0.2
0.4
0.6
0.8
ωτ=1
ωτ=0.5
ωτ=0.2
ωτ=0.01
ωτ=0.005
ωτ=0.002
σ'(T)/σ_L''(0)
T/T_C
0.25
0.5
0.75
1
0
0.1
0.2
0.3
0.4
0.5
ωτ=1
ωτ=0.5
ωτ=0.2
ωτ=0.1
ωτ=0.05
ωτ=0.002

Diagram of the microwave cavity used in the 'hot-finger' technique

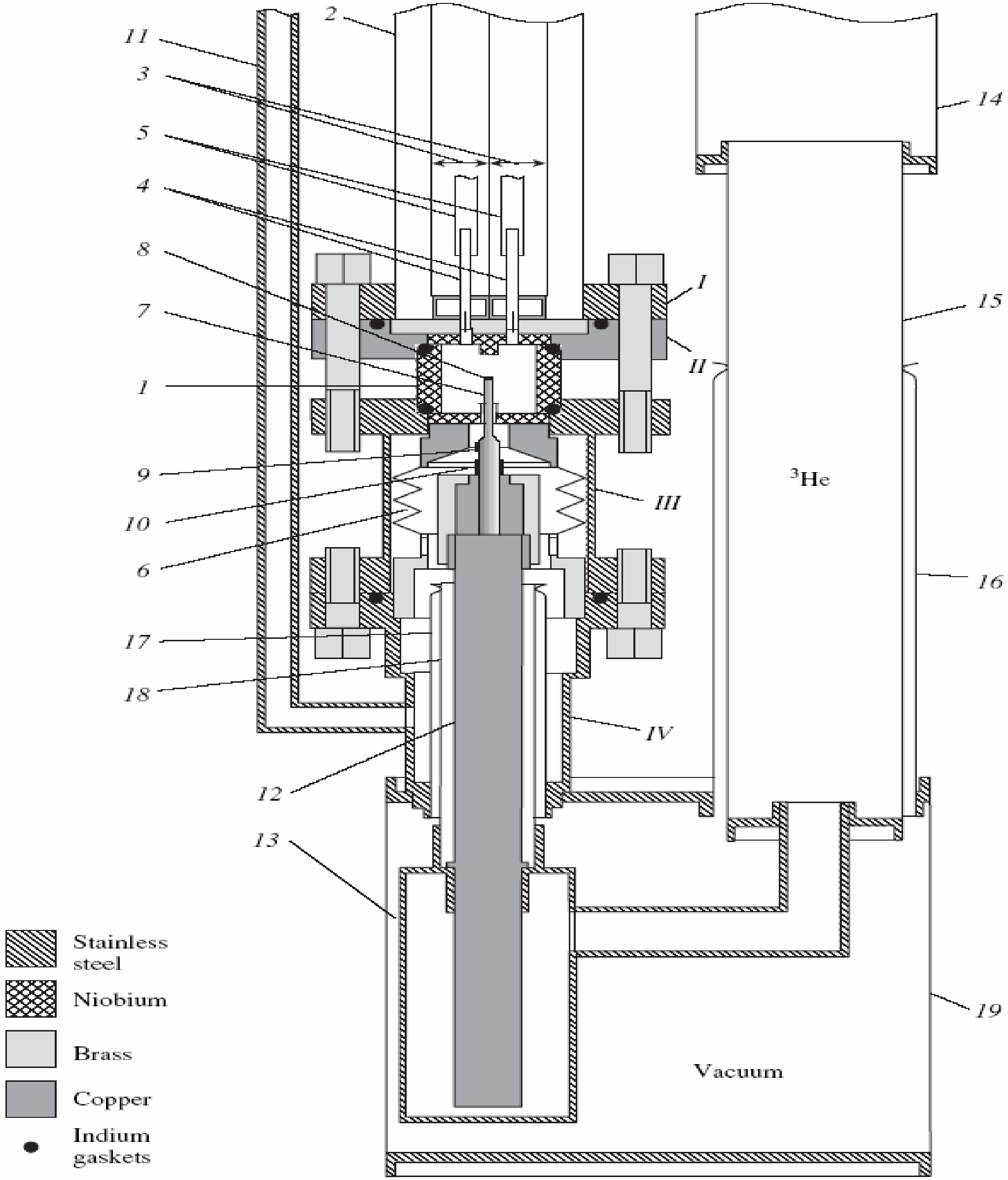


$$\mathbf{E}_t = Z[\mathbf{H}_t \mathbf{n}]$$
$$Z = R + \imath X$$

$$R(T) = \Gamma\left(\frac{1}{Q} - \frac{1}{Q_0}\right)$$
$$X(T) = -\Gamma\left(\frac{2\Delta f - 2\Delta f_0}{f_0}\right) + X_0$$
$$\Gamma = \frac{\omega\mu_0 \int_V H_\tau^2 dV}{\int_S H_\tau^2 dS}$$

$$\sigma' = \omega\mu_0 \frac{2RX}{(R^2 + X^2)^2}$$
$$\sigma'' = \omega\mu_0 \frac{X^2 - R^2}{(R^2 + X^2)^2}$$

Fig. 1. Design of the insert's part placed inside the cryostat: (*1*) niobium resonator, (*2*) tube, (*3*) waveguides, (*4*) coupling elements, (*5*) links, (*6*) bellows, (*7*) sapphire rod, (*8*) sample, (*9*) thermometer, (*10*) heater, (*11*) thick-walled tube, (*12*) copper rod, (*13*) collector of liquid ^{3}He, (*14*, *15*) ^{3}He-supplying tubes, (*16*–*19*) tubes of the vacuum jacket, and (*I*–*IV*) parts of the resonator unit.



M.Trunin, Physics-Uspekhi ***41****, 843 (1998);* ***48,*** *989 (2005)*
A.Shevchun, M.Trunin, Instruments and Experimental Techniques ***49,*** *669 (2006)*

<u>At $T > T_c$</u>

$$\rho(T) = 2R^2(\mathrm{T})/\omega\mu_o$$

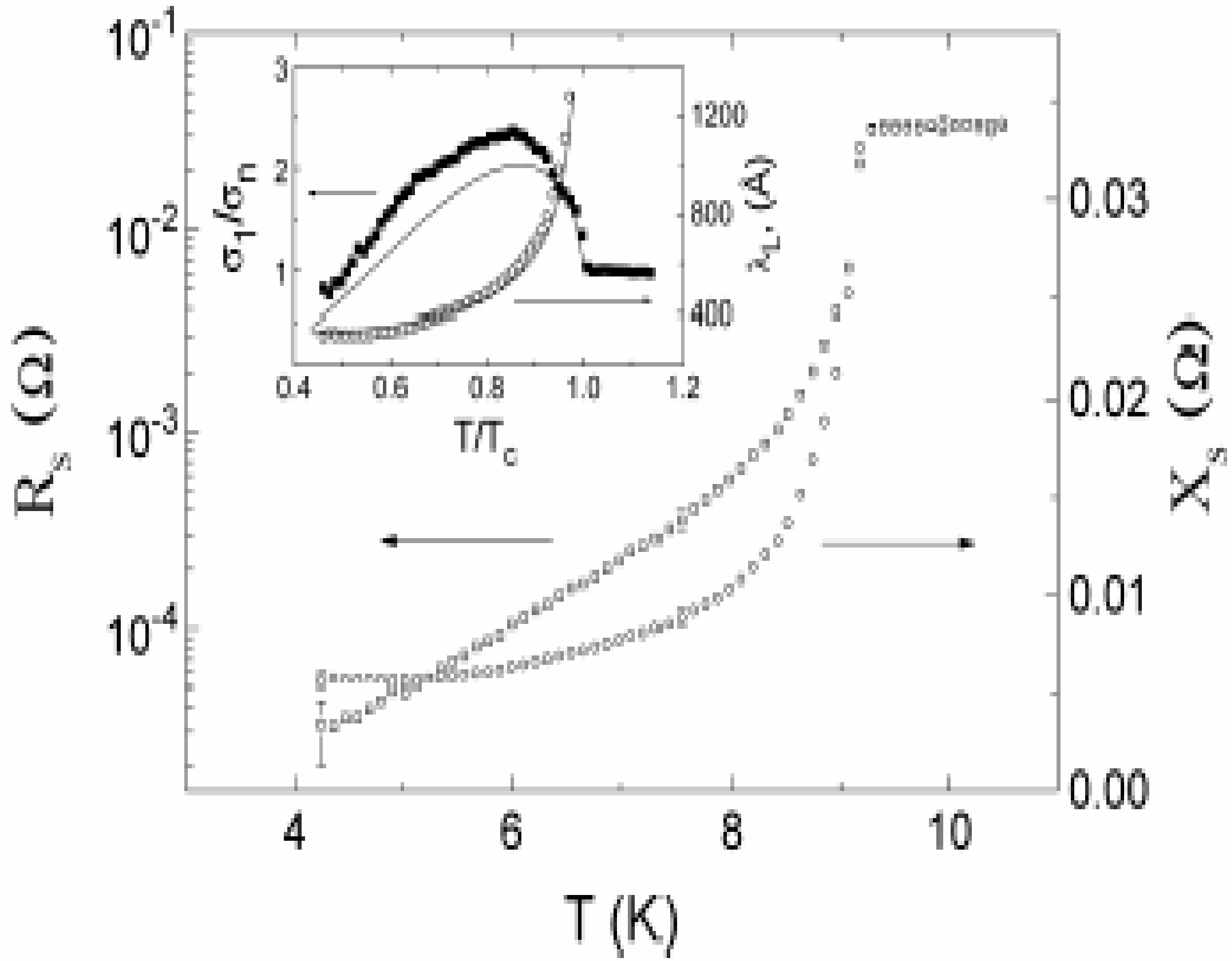
<u>At $T < T_c$</u>

$$R = \frac{1}{2}\mu_o^2\omega^2\lambda^3\sigma_1$$

$$X = \mu_o\omega\lambda$$

$$\lambda = (1/\omega\mu_o\sigma_2)^{1/2}$$

Surface impedance and conductivity in dirty Nb at 9.3 GHz

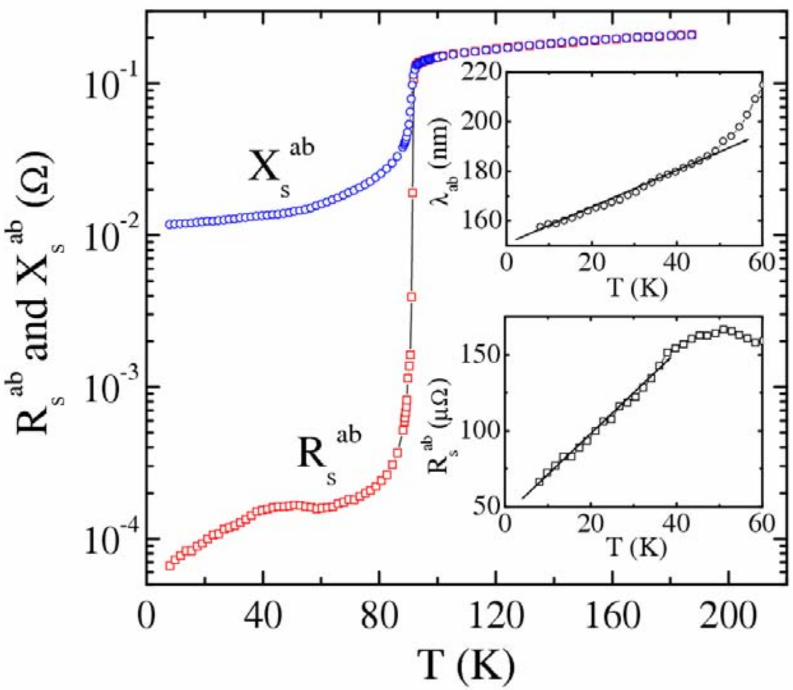


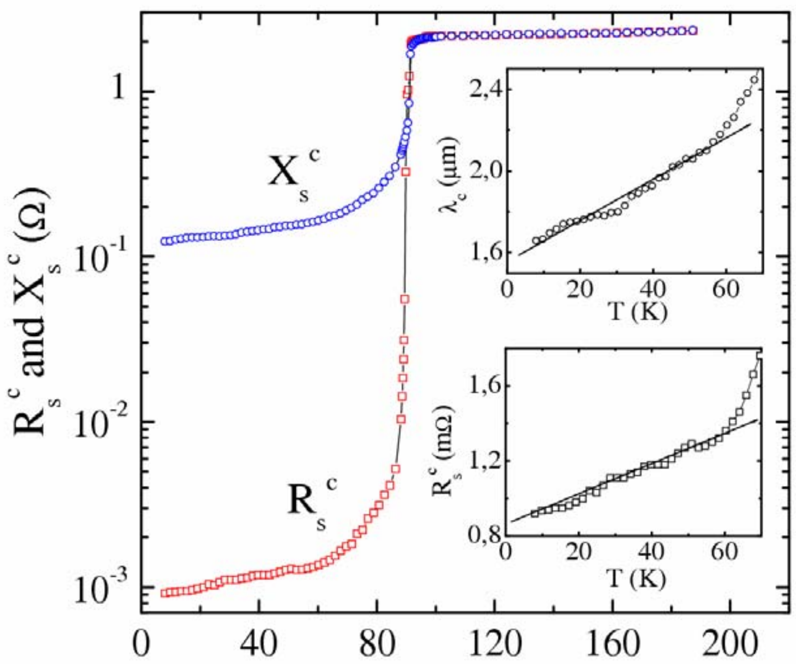
The accuracy is ≈ 1 nm in λ(0), and ≈ 10 μΩ in $R_{res} = R(T\to 0)$

$\rho(T_c) \approx 3\mu\Omega\cdot$cm,
$\tau(T_c) \approx 2\cdot 10^{-14}$ s,
$\ell(Tc) \approx 4$ nm,
$\lambda_L(0)=\lambda(0)\sqrt{\ell/\xi o}$
≈ 32 nm
$R_{res} \approx 20\mu\Omega$

Surface resistance (red lines) and reactance (blue lines) in the *ab*-planes (at the left) and along *c*-direction (at the right) of optimally doped $YBa_2Cu_3O_{6.93}$ single crystal at 9.3 GHz

Yu.Nefyodov, M.Trunin, A.Zhohov et al. PRB ***67****, 144504 (2003)*

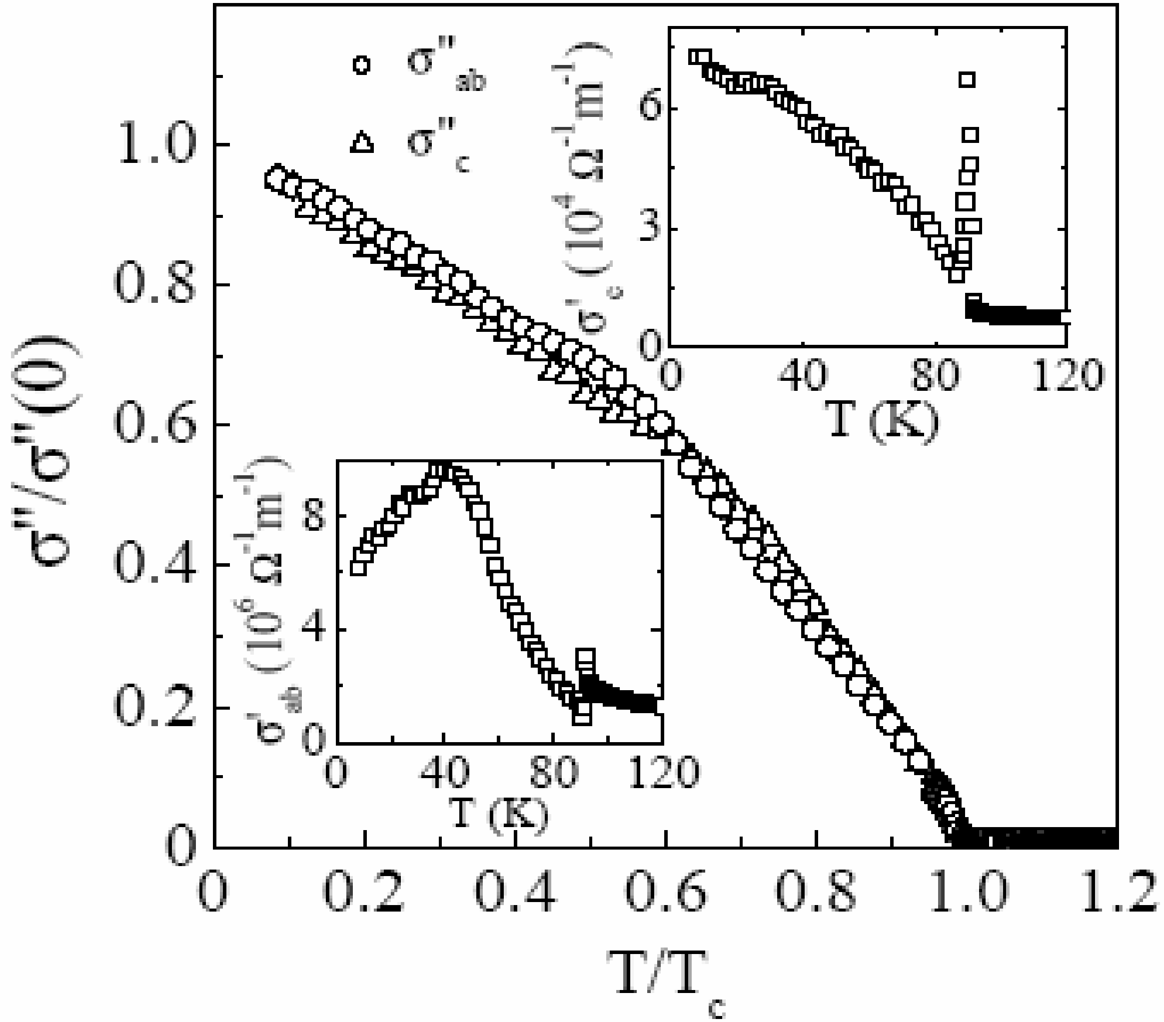




$R_{ab}(0) \approx 40\mu\Omega$, $\lambda_{ab}(0) \approx 150$ nm

$R_c(0) \approx 800\mu\Omega$, $\lambda_c(0) \approx 1.55$ μm

The conductivities $\sigma''_{ab}/\sigma''_{ab}(0)$ and $\sigma''_c/\sigma''_c(0)$ of $YBa_2Cu_3O_{6.93}$ single crystal versus T/T_c.

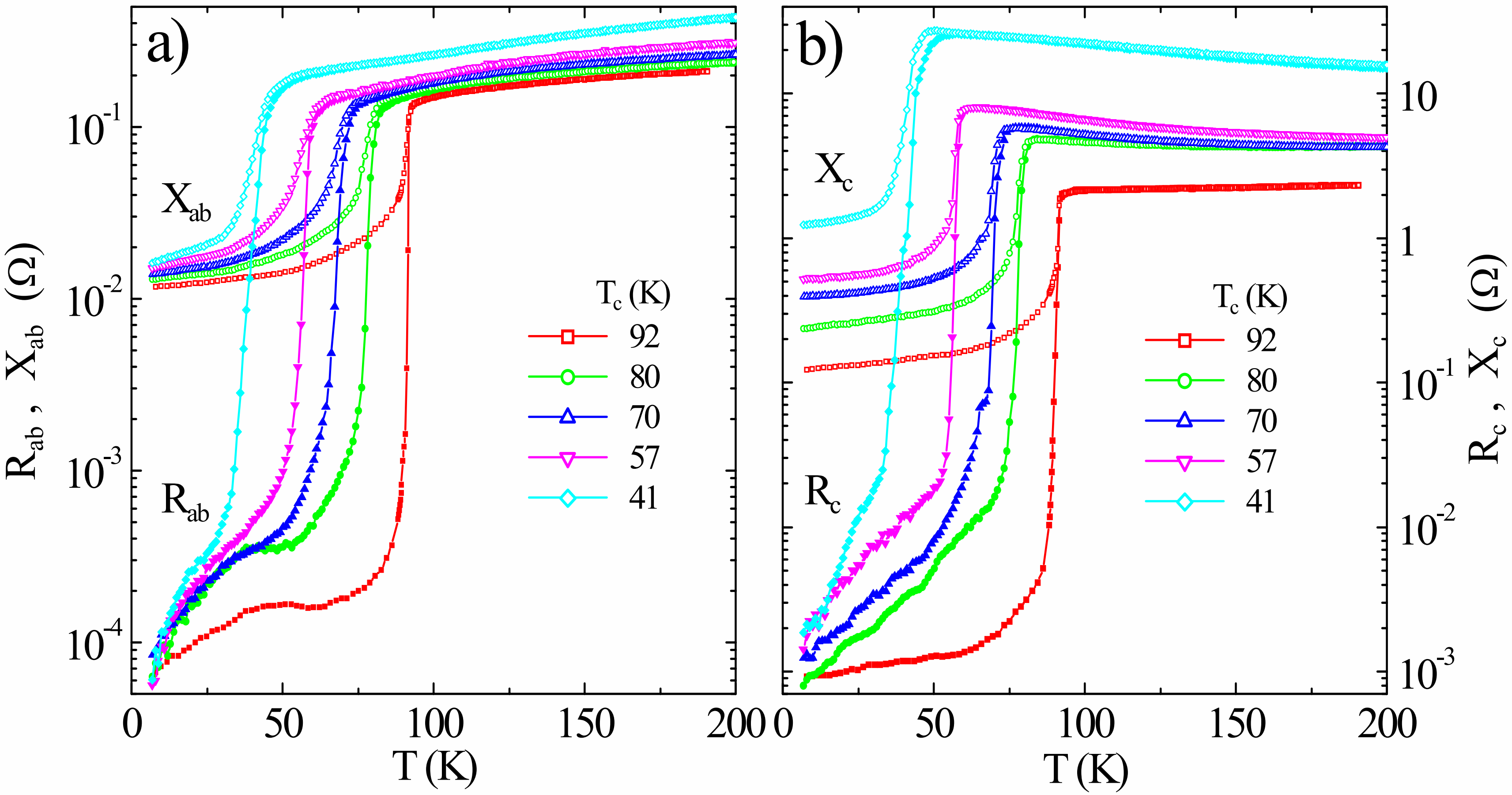


$\sigma'(T)$

has a maximum at $T < T_c$ if

$$R_{res} < \frac{X(0)}{3} \frac{dR(T)}{dX(T)}\bigg|_{T\to 0}$$

(a) Real $R_{ab}(T)$ and imaginary $X_{ab}(T)$ parts of the *ab*-plane surface impedance of the five states of $YBa_2Cu_3O_{7-x}$ single crystal; (b) the components of the *c*-axis surface impedance

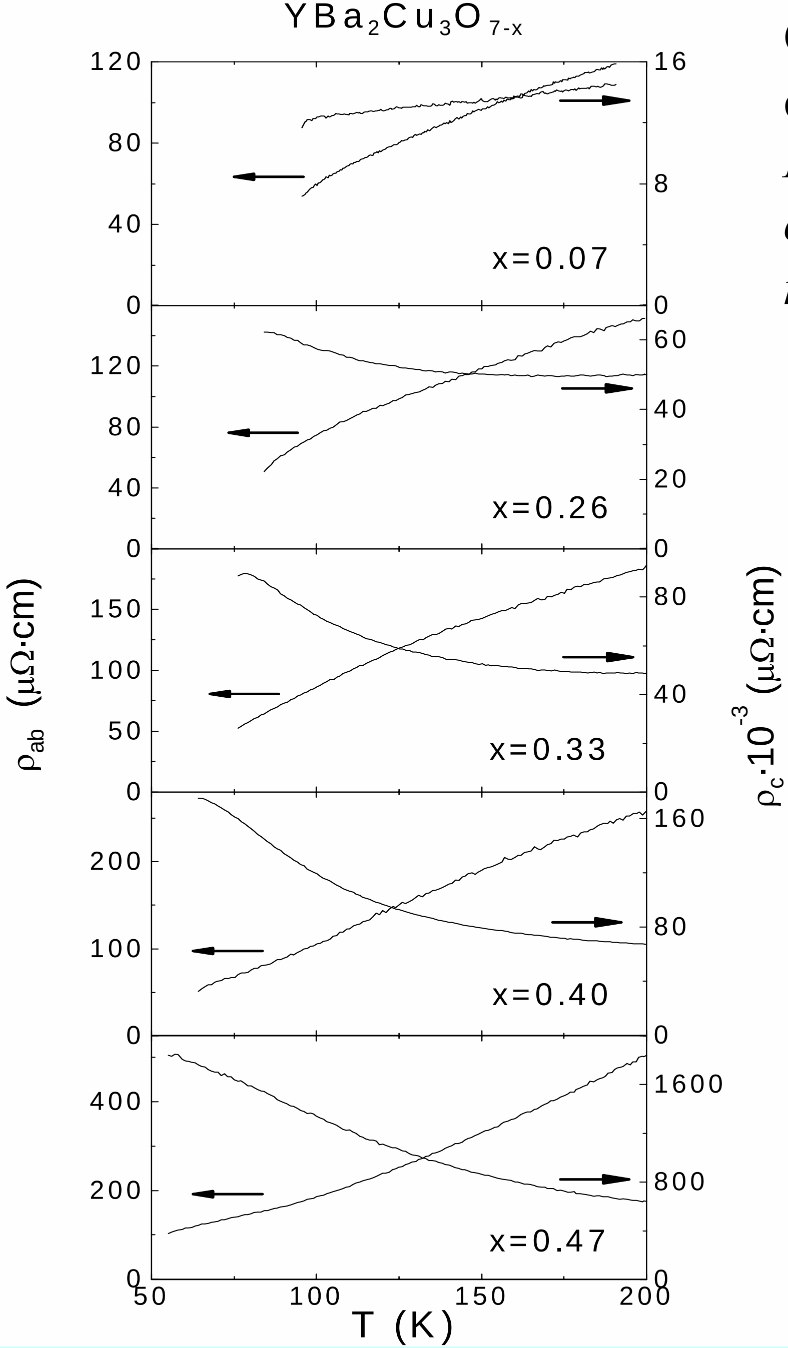


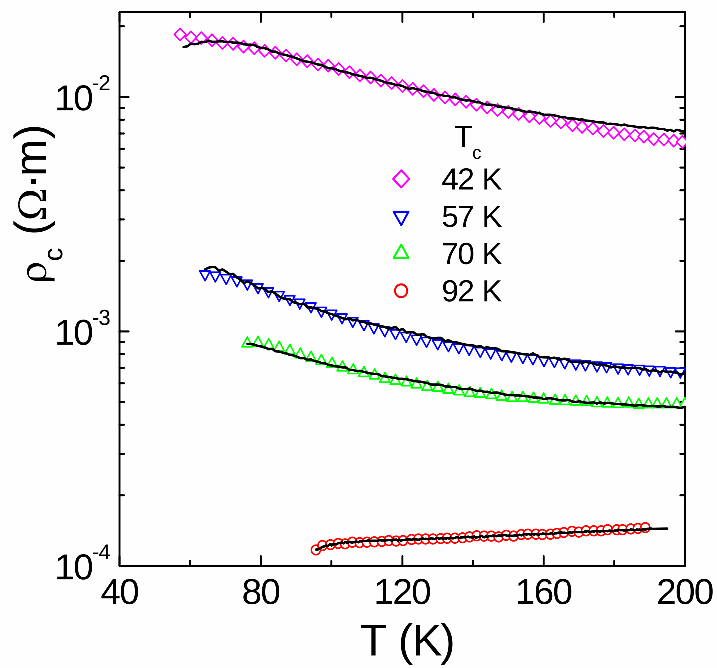
Crossover 3D-2D in $YBa_2Cu_3O_{7-x}$: from Drude c-axis conductivity to the hopping one

M.Trunin and Yu.Nefyodov, JETP Lett. ***77****, 592 (2003)*

$\sigma_{ab}\sigma_{c,max} \approx (n_{2D}/\pi)(e^2/\hbar)^2$, $\sigma_{c,max} \approx \sigma_{IR}(\rho_{ab}/\rho_c)^{0.5}$,

$n_{2D} = n/d \approx 10^{14}$ см$^{-2}$ => $\underline{\rho_{ab}\rho_c \approx 10^{-6}\ \text{Ом}^2\text{см}^2}$

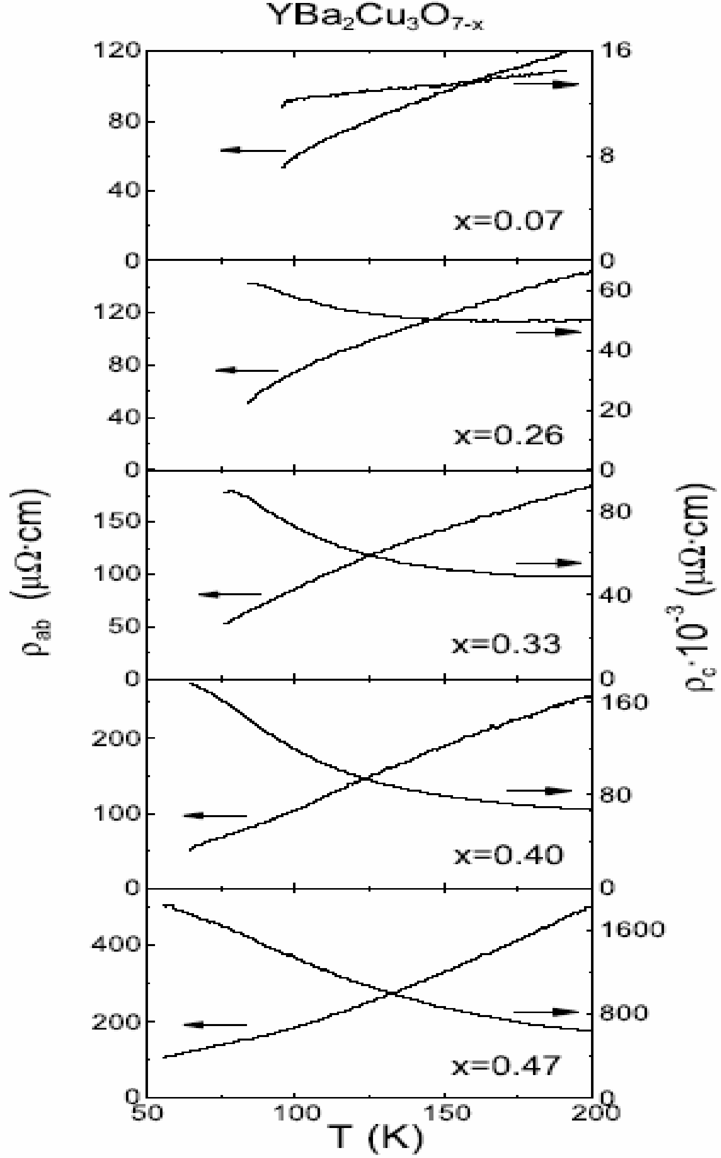


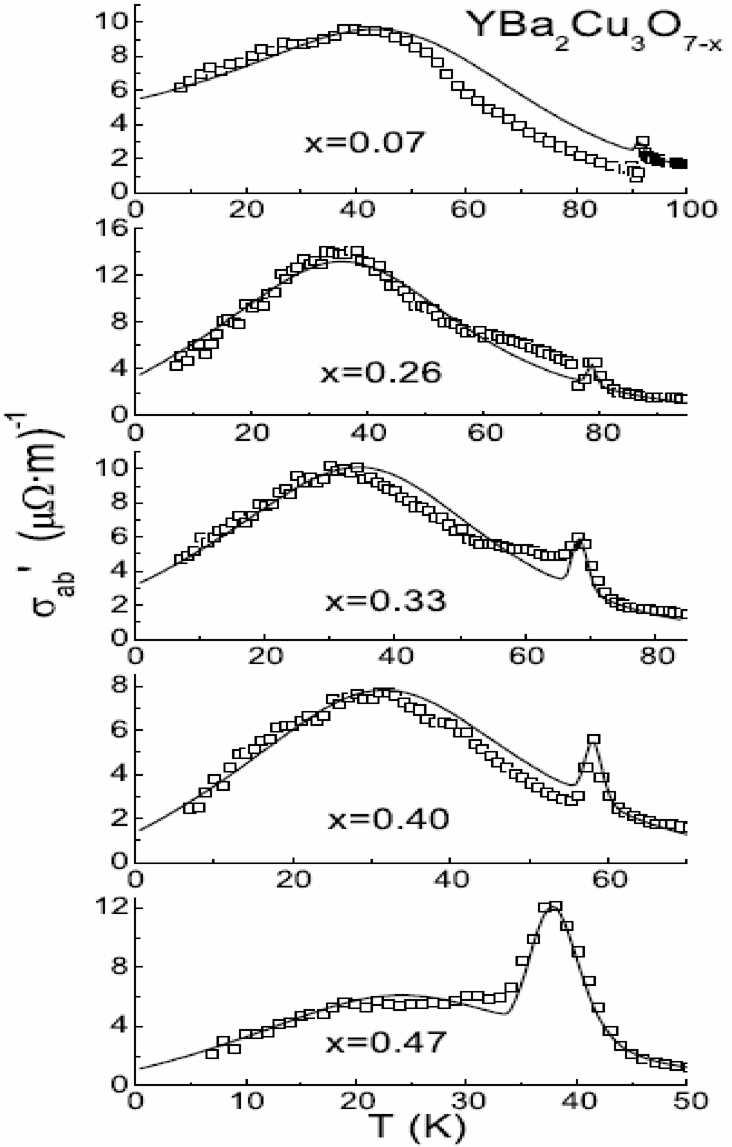


A.Ho and A.Schofield cond-mat/ 0211675

$$\rho_c(T) \sim \rho_{ab}(T)\frac{\exp[g^2\tanh(\omega_0/4T)]}{[\sinh(\omega_0/2T)]^{1/2}}$$

The evolution of the measured dependences of conductivity in $YBa_2Cu_3O_{7-x}$ crystal in the normal (left) and superconducting state (right)

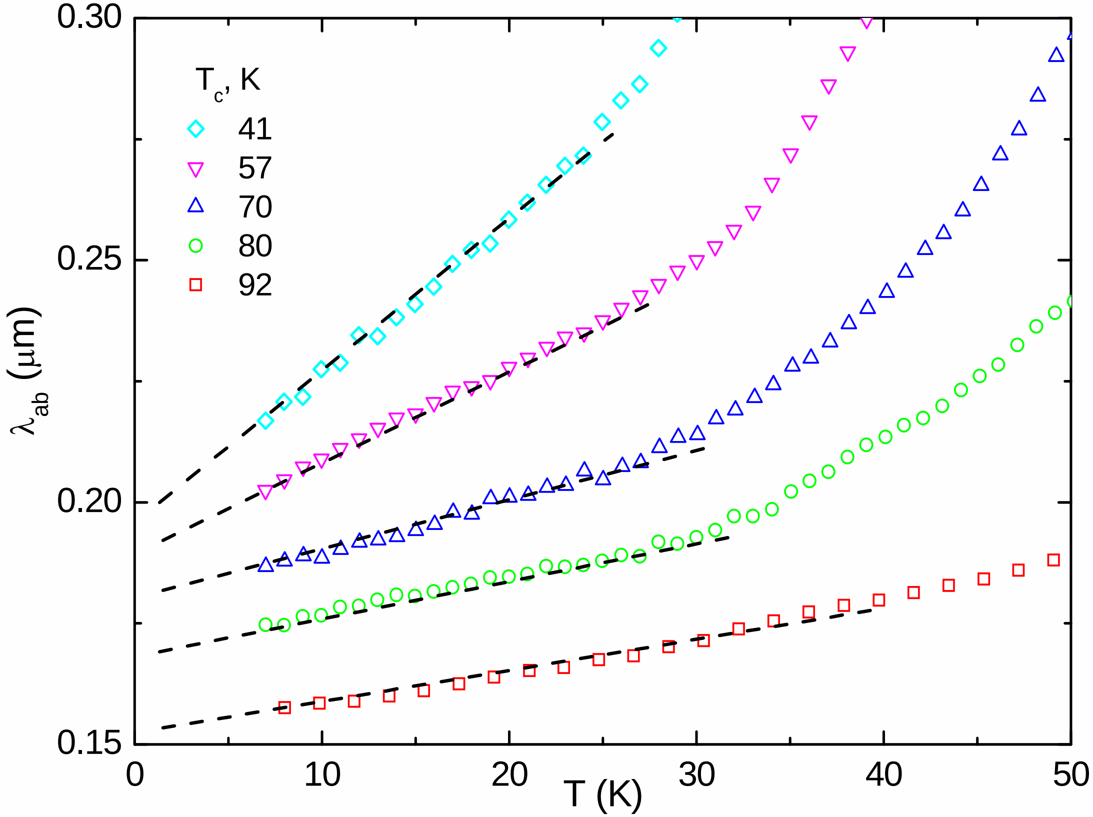




annealing temperature t, ^{o}C	critical temperature T_c, K	doping parameters p	x	zero temperature penetration depths λ_{ab}, nm	λ_c, μm	$\delta\lambda_c(T)\propto T^{\alpha}$ α	λ_c/λ_{ab} at T=0
500	**92**	**0.160**	**0.07**	**152**	**1.55**	**1.0**	**10**
520	**80**	**0.120**	**0.26**	**170**	**3.0**	**1.1**	**18**
550	**70**	**0.106**	**0.33**	**178**	**5.2**	**1.2**	**29**
600	**57**	**0.092**	**0.40**	**190**	**6.9**	**1.3**	**36**
720	**41**	**0.078**	**0.47**	**198**	**16.3**	**1.8**	**83**

$$T_c=T_c^{max}[1-82.6\cdot(p-0.16)^2]$$

Low-temperature dependences of $\lambda_{ab}(T)$ (open symbols) measured for five states of the $YBa_2Cu_3O_{7-x}$ crystal with $T_c = 92$ K, $T_c = 80$ K, $T_c = 70$ K, $T_c = 57$ K, and $T_c = 41$ K. Dashed lines are linear extrapolations at $T < T_c/3$



≈ 5 nm accuracy in the $\lambda_{ab}(0)$ value

M. Trunin, Yu. Nefyodov, and A. Shevchun, Phys. Rev. Lett. ***92****, 067006 (2004)*

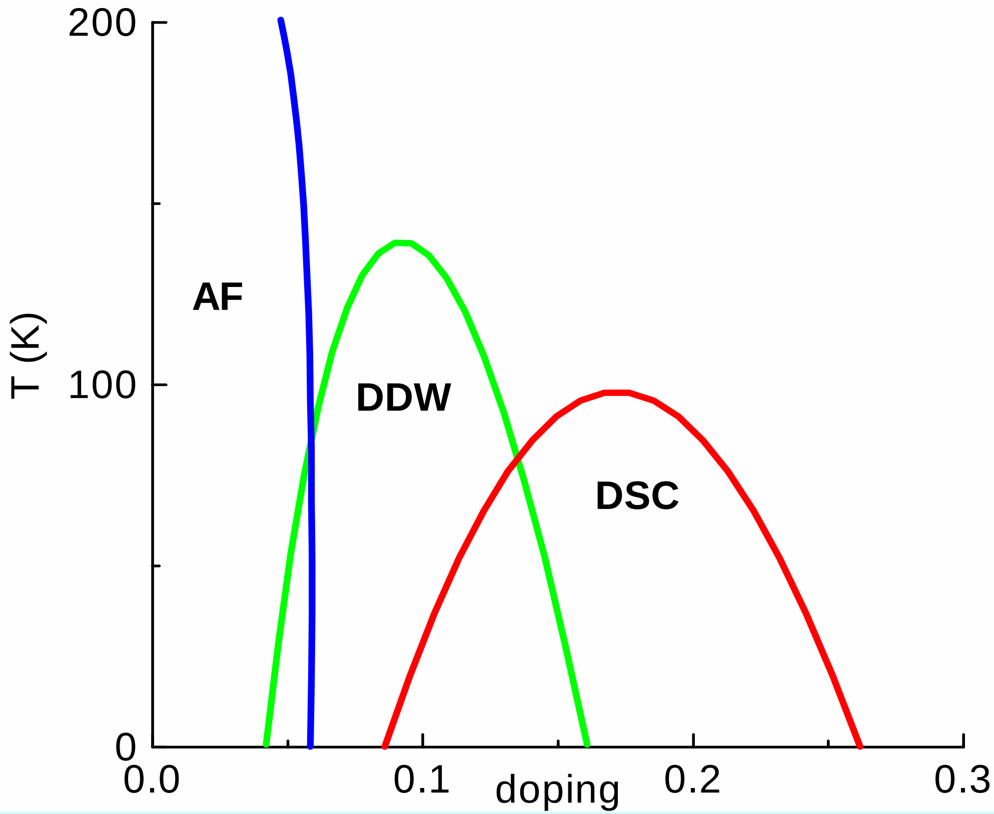
Superfluid density: $n_s = \frac{m}{\mu_0 e^2 \lambda_{ab}{}^2}$, $\Delta n_s(T,p) \sim -\Delta\lambda_{ab}(T,p)$

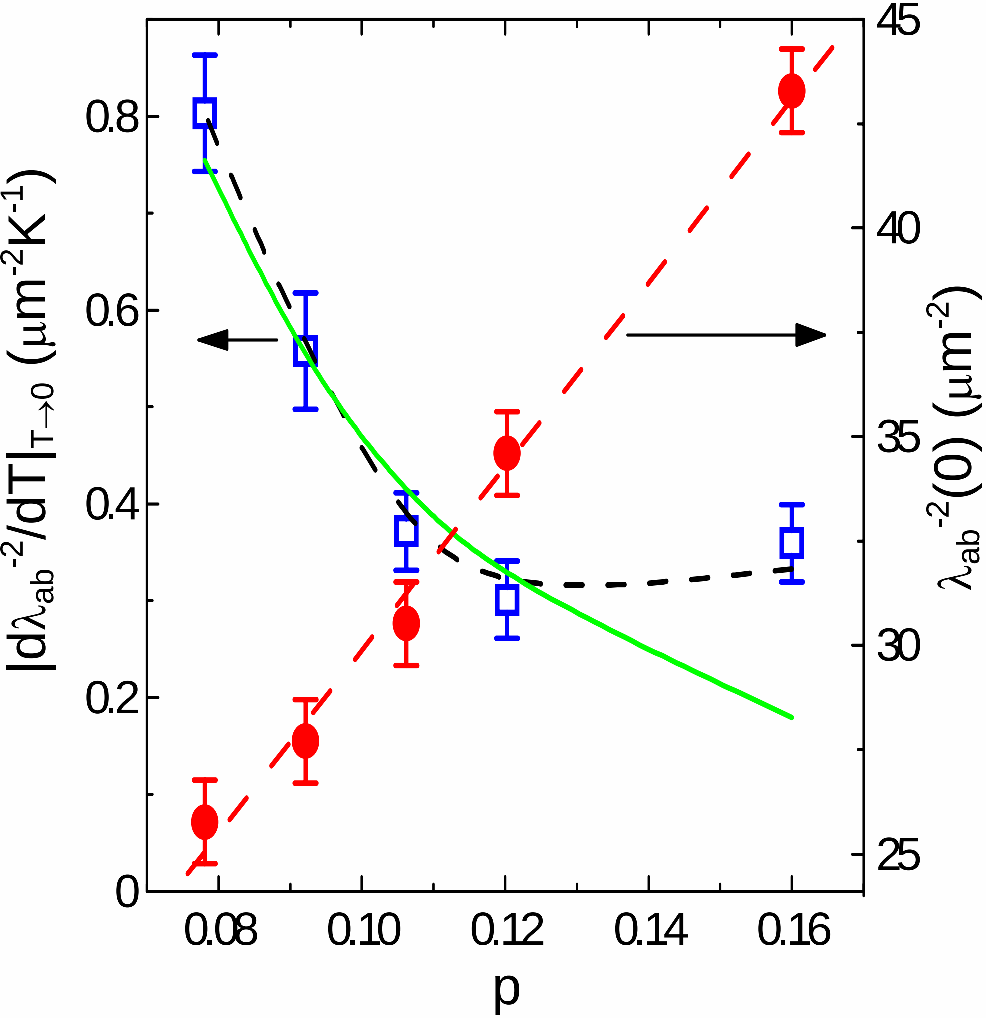
BCS d-wave superconductor (DSC): $n_s(T) = n_s(0)\left[1 - \frac{\alpha T}{\Delta_0}\right]$, $\alpha = \text{const}$ DSC slope: $\left| dn_s / dT \right|_{T\to 0} = \frac{\alpha\, n_s(0)}{\Delta_0}$

Pseudogap + DSC

Parameters of underdoped HTSC $T \ll T_c$ $0.05<p<0.16$	Generalized Fermi-liquid GFL+DSC Lee, Larkin, Ioffe, Millis, …	Magnetic precursor DDW Chakravarty, Laughlin, Nayak	Precursor pairing BEC Levin, Legget, Emery, …
$n_s(0,p)$	~p	~p	~p
$\left\| \frac{dn_s}{dT} \right\|_{T\to 0}$ with underdoping	$\sim \frac{L(p)}{\Delta_0(p)}$ const (Lee) increases $\sim \frac{1}{p^2}$ (Larkin)	$\sim \frac{\alpha\, n_s(0,p)}{\Delta_0(p)}$ const (0.1<p<0.16) rapidly grows (p<0.1)	$\sim \frac{\alpha\, n_s(0,p)}{\Delta_0(p)}$ slightly decreases
$\left[\frac{n_s(T)}{n_s(0)}\right] - 1$	~T	~T (0.1<p<0.16) ~T, T<Tc/10 $\sim \sqrt{T}$, $\frac{T_c}{10} < T < \frac{T_c}{2}$ (p<0.1)	~T

The temperature versus doping *p* schematic phase diagram based on calculations of [*Nayak, Pivovarov. PRB* **66**, *064508 (2002)*].
AF is the 3D antiferromagnetic phase. The system is an isolator in the AF state, a metal in the DDW and DDW + AF states, and a superconductor in the DSC and DDW+DSC states

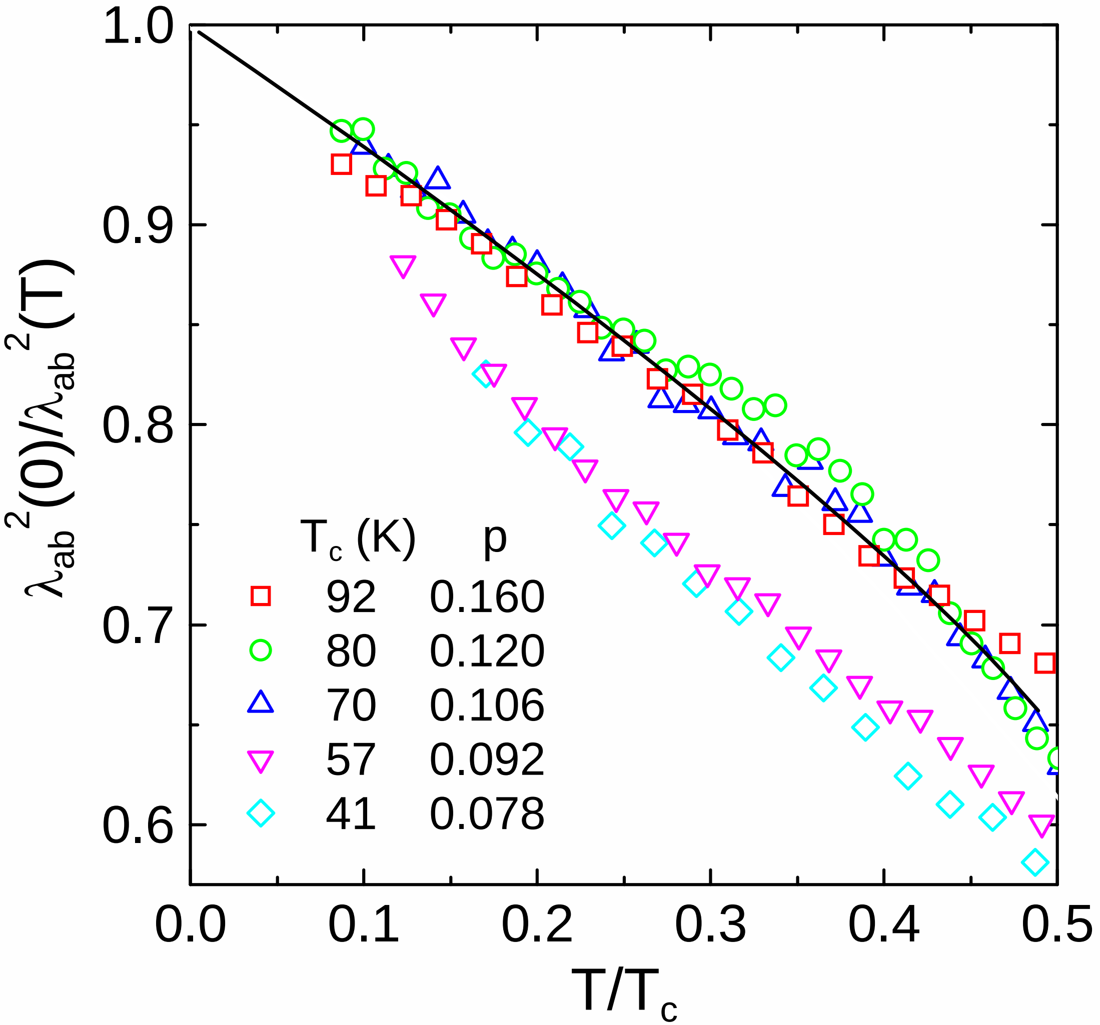




The values of $\lambda^{-2}{}_{ab}(0) = n_s(0)\mu_o e^2/m^*$ (right scale) and slopes $|d\lambda^{-2}{}_{ab}(T)/dT\,|_{T\to 0} = \mu_0 e^2/m^*|dn_s(T)/dT\,|_{T\to 0}$ (left scale) as a function of doping p in $YBa_2Cu_3O_{7-x}$. Error bars correspond to experimental accuracy. The dashed and dotted curves guide the eye.The solid green curve is the $|dn_s(T\,)/dT|$ □ p^{-2} dependence.

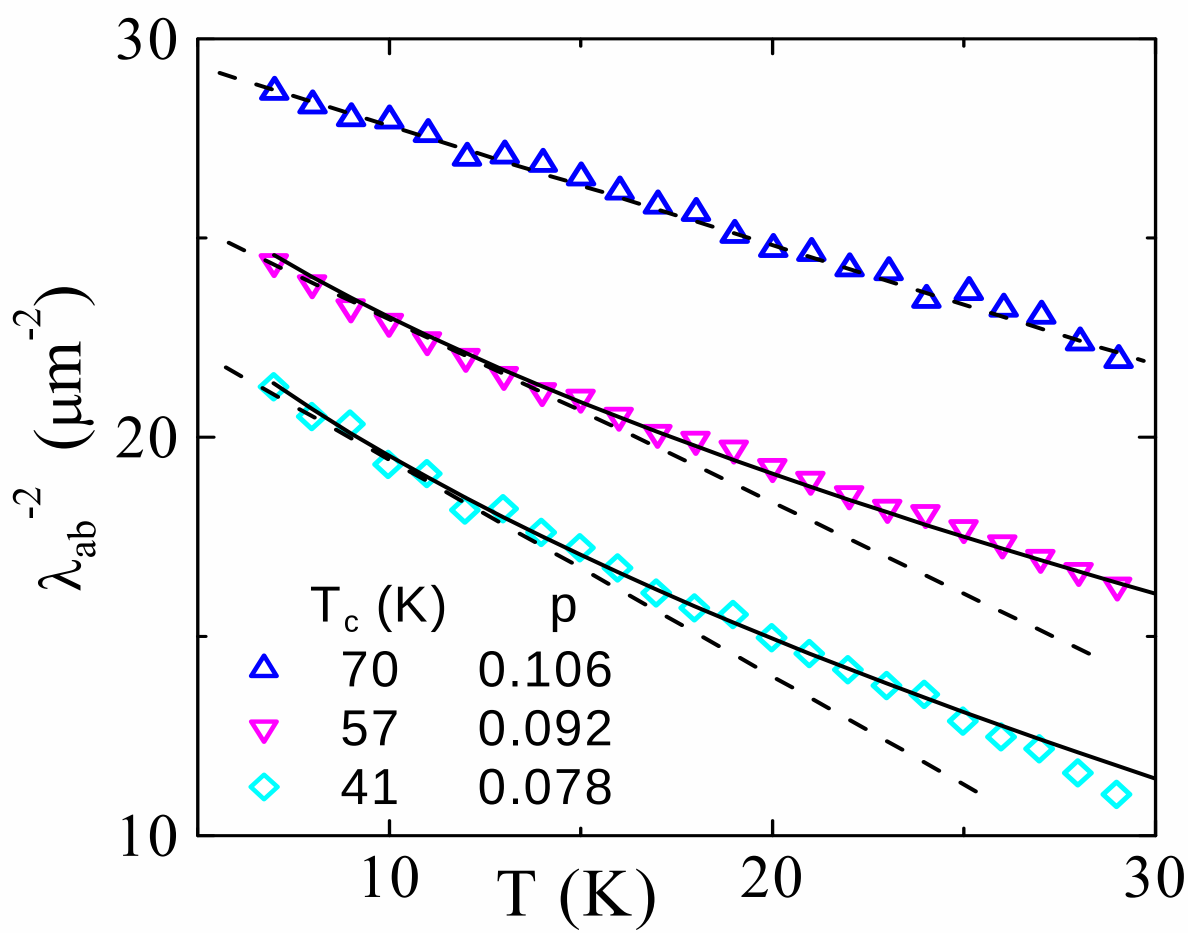
“Most problematically, the model (*d*-wave RVB) predicts a strong doping dependence to the leading low-*T* correction to the London penetration depth $d\lambda_{ab}^{-2}/dT \propto p^{-2}$ which is not observed” [*Ioffe, Millis. PRB* ***66****, 094513 (2002)*]

Imaginary part of conductivity at $T<T_c/2$ in the *ab*-planes of $YBa_2Cu_3O_{7-x}$ crystal with different doping. The solid line corresponds to clean *d*-wave superconductor

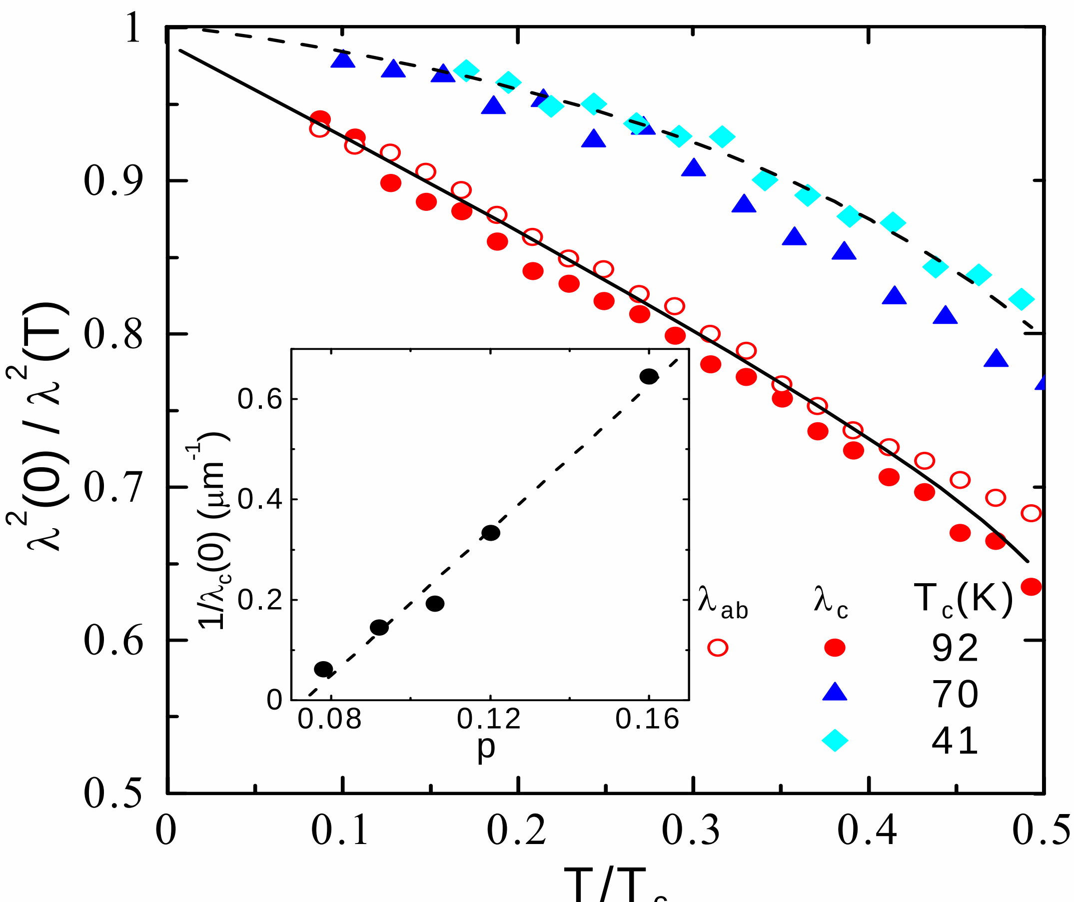


The concavity of *σ″(T)* curves for the heavily undorped states evidences the *d*-density wave scenario of pseudogap in HTSCs

Comparison of experimental $n_s(T)$ curves (symbols) with linear $n_s(T)$□$(-T)$ (dashed lines) and root $n_s(T)$□$(-\sqrt{T})$ (solid curves) dependences for moderately doped ($p = 0.106,\ x = 0.33$) and heavily underdoped ($p=0.092,\ x=0.40;\ p=0.078,\ x=0.47$) $YBa_2Cu_3O_{7-x}$



The dependence $\lambda^2_{ab}(0)/\lambda^2_{ab}(T)$ (open symbols) in $YBa_2Cu_3O_{7-x}$ and $\lambda^2_c(0)/\lambda^2_c(T)$ (full symbols) measured for three states of the $YBa_2Cu_3O_{7-x}$ crystal with T_c = 92, 70 and 41 K. Solid and dashed curves stand for the dependences $\lambda^2_c(0)/\lambda^2_c(T)$ calculated in [*Rojo, Levin. PRB* ***48****, 16861 (1993)*] for $YBa_2Cu_3O_{7-x}$ with different oxygen deficiency. The inset shows $1/\lambda_c$ at $T = 0$ as a function of doping p



The reduction in the low-T slope of $\lambda^2_c(0)/\lambda^2_c(T)$ curves and the appearance of semiconducting-like temperature dependence of $\rho_c(T)$ caused by a decrease of the interlayer coupling in the crystal.

M.Trunin, Yu.Nefyodov, A.Shevchun. Supercond. Sci. Technol. ***17****, 1082 (2004)*

CONCLUSION I

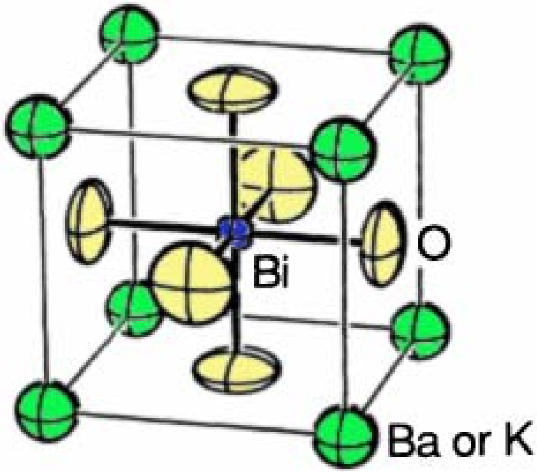
Thus, three main experimental observations of $YBa_2Cu_3O_{7-x}$, viz,

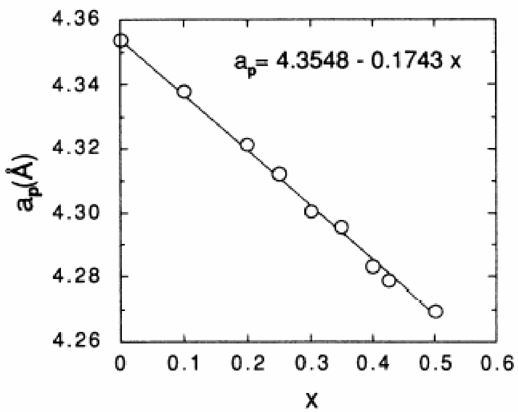
(i) drastic increase of low-temperature $n_s(T)$ slope at $p<0.1$,
(ii) the deviation of $\Delta n_s(T)$ dependence from universal BCS behavior $\Delta n_s(T) \propto (-T)$ at $T<T_c/2$ towards $\Delta n_s(T) \propto (-\sqrt{T})$ with decreasing $p<0.1$, and
(iii) very weak influence of pseudogap on the low-T and doping dependences of the *c*-axis penetration depth evidence the DDW scenario of electronic processes in underdoped HTSC.

Nevertheless, the measurements of $\lambda_{ab}(T)$ and $\lambda_c(T)$ at lower temperatures and in the high-quality samples with smaller carrier density are necessary for ultimate conclusion.

Crystal structure of $Ba_{1-x}K_xBiO_3$

Pei et al. PRB ***41,*** *4126 (1990)*





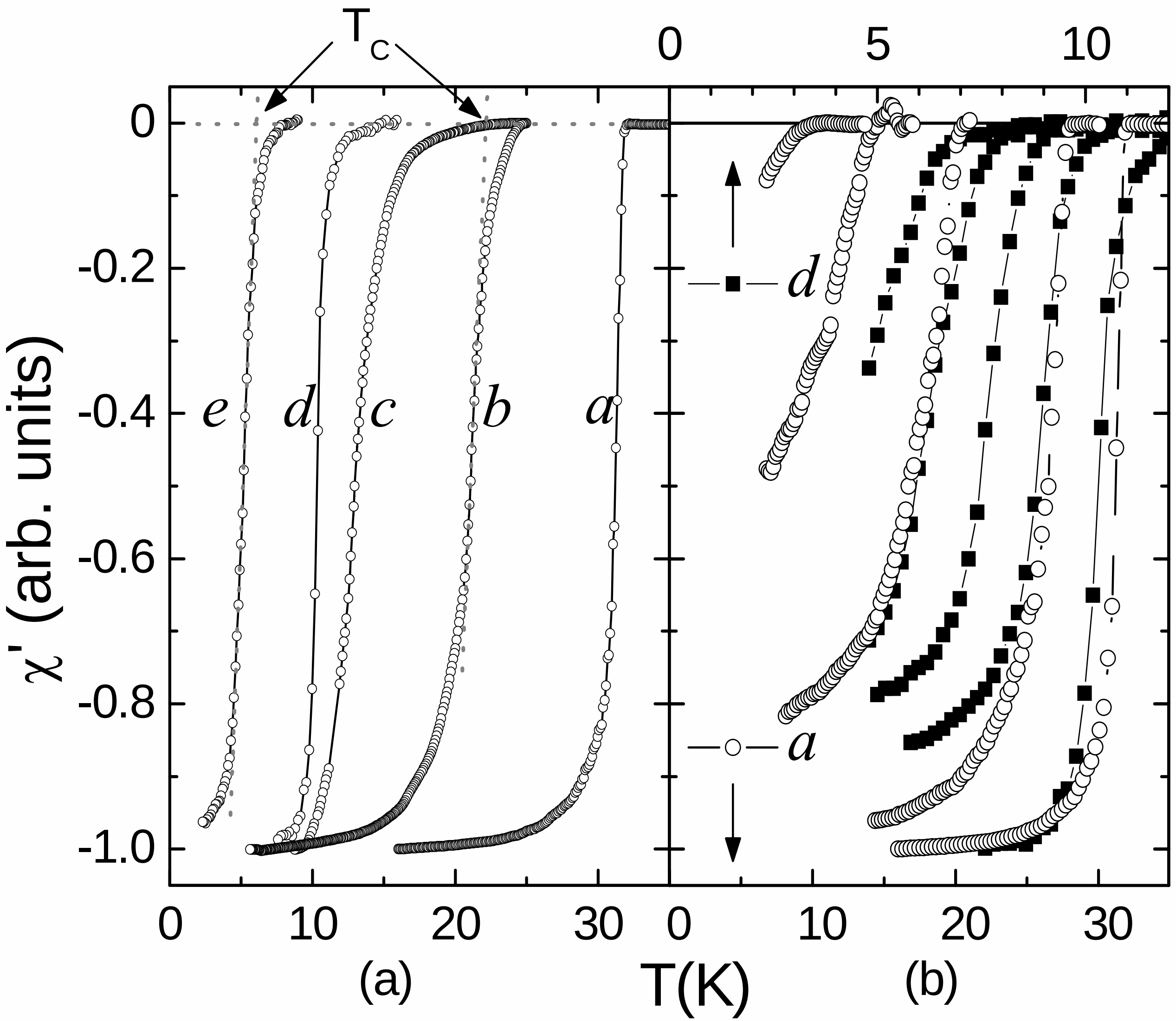
$0 < x < 0.13$ monoclinic structure

$0.13 < x < 0.37$ orthorhombic structure

} isolator

$x > 0.37$ cubic structure — metal

ac susceptibility of $Ba_{1-x}K_xBiO_3$ (0.4 < x < 0.6) single crystals

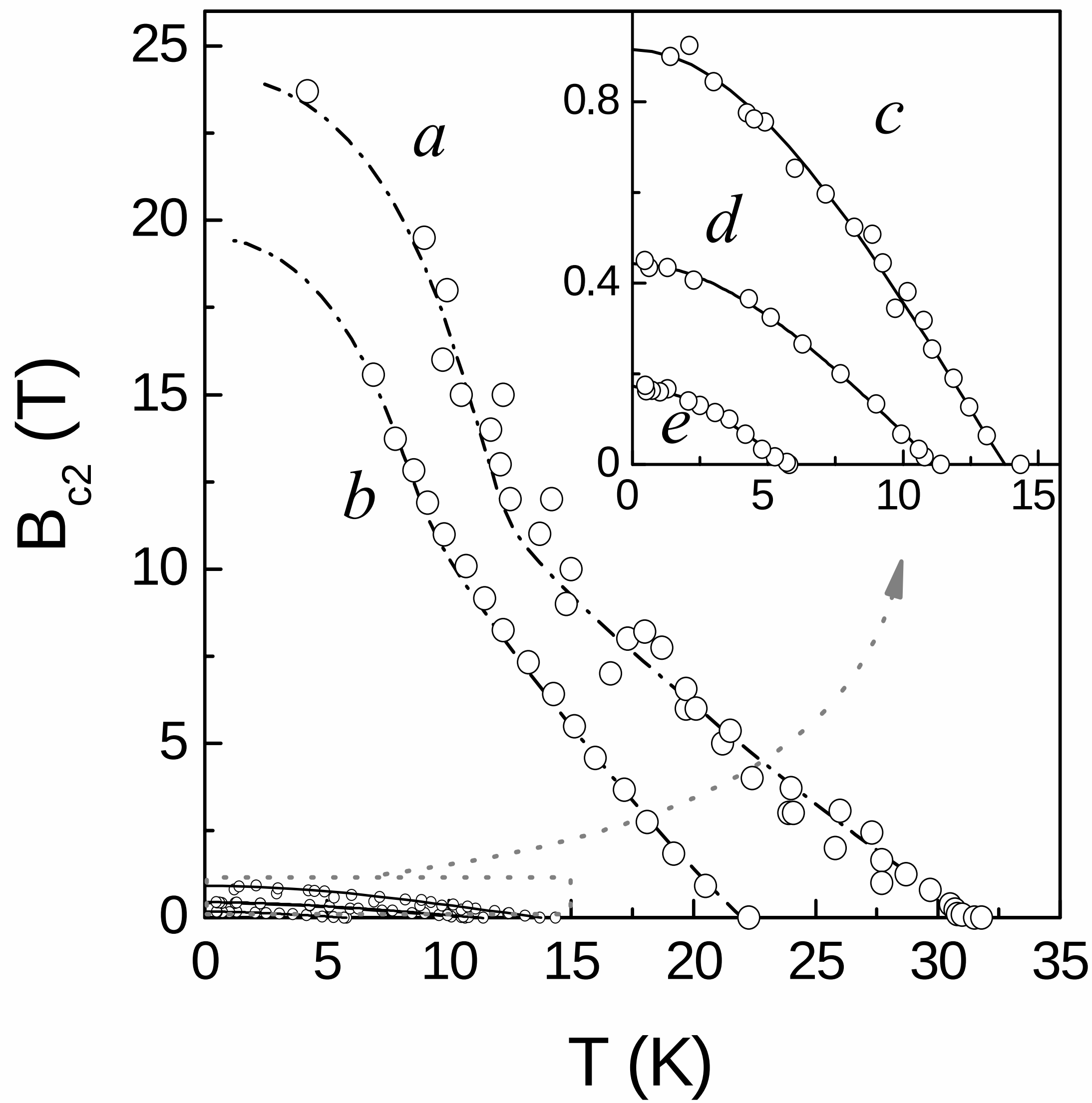


$B = 0$ $B \neq 0$

The field values (from right to left) for sample *a*: B = 0, 1, 6, 12 and 19.5 T; for sample *d*: H = 0, 0.067, 0.133, 0.2 and 0.27 T

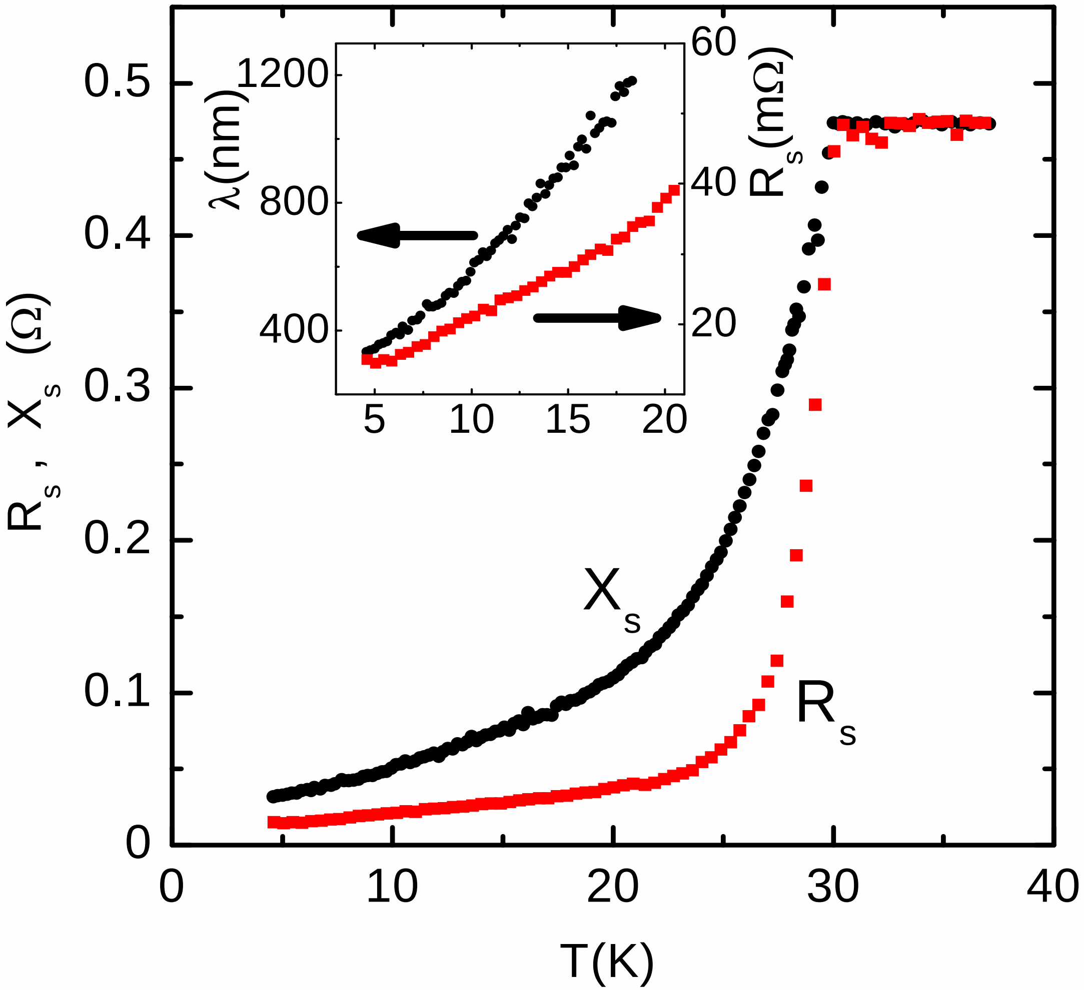
G.Tsydynzhapov, A.Shevchun, M.Trunin, V.Zverev, D.Shovkun et al., JETP Letters ***83****, 405 (2006)*

Upper critical fields $B_{c2}(T)$ in $Ba_{1-x}K_xBiO_3$ single crystals
a - e with $5K < T_c < 32K$ $(0.35 < x < 0.55)$



Solid lines show BCS model;
Dash-dotted lines show extended saddle-point model of *A.Abrikosov, PRB **56**, 5112 (1997)*

Surface impedance of $Ba_{1-x}K_xBiO_3$ single crystal with $T_c \approx 30$ K ($x \approx 0.4$) at 9.4 GHz



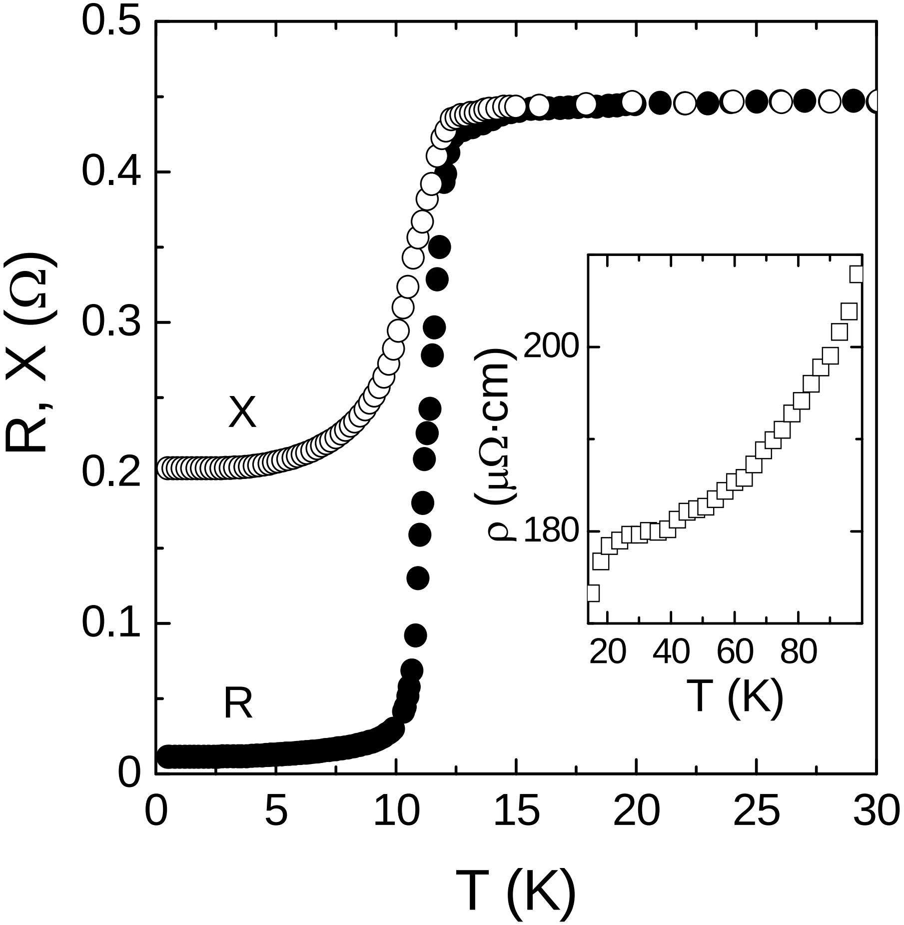
$\lambda(0) \approx 300$ nm $>> \xi_o$,

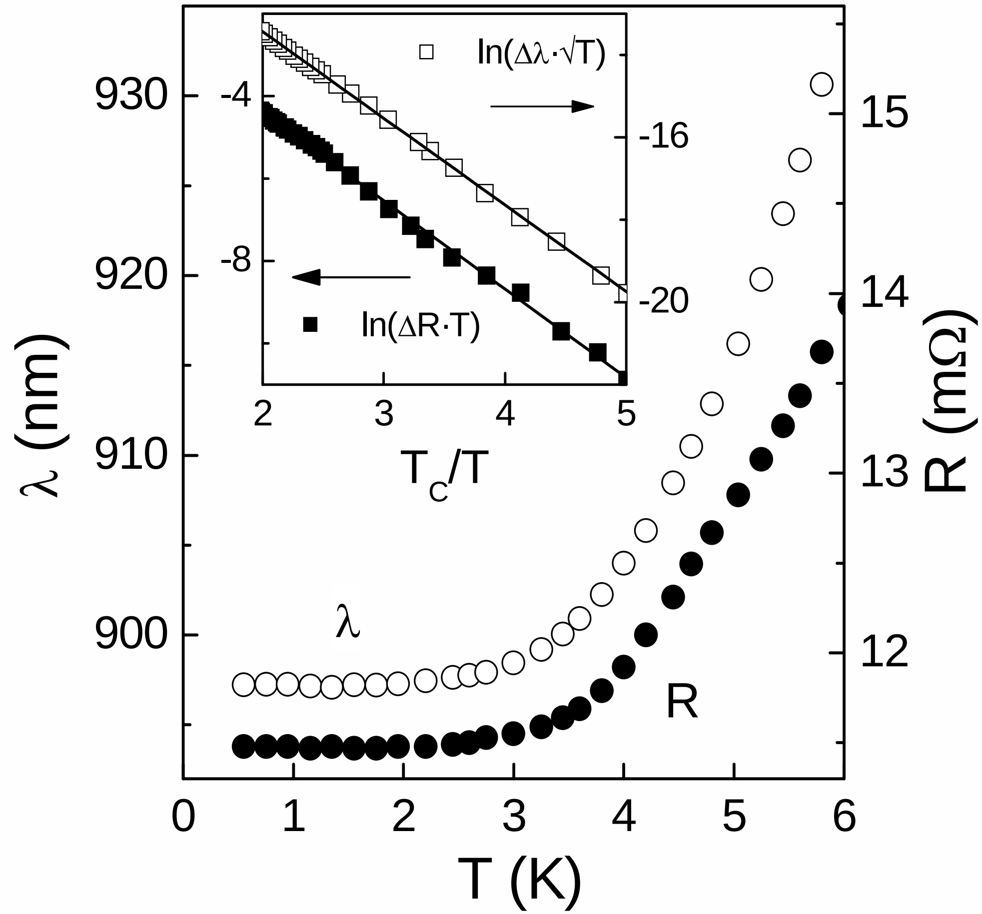
$\rho(T_c) \approx 600$ μΩ·cm,

$\tau(T_c) = X^2(0)/2\omega R(T_c) \approx 2\cdot 10^{-14}$ c

$l(T_c) \sim \xi_o$, $R_{res} \approx 10$ mΩ

The impedance of $Ba_{1-x}K_xBiO_3$ single crystal with $T_c \approx 11$ K ($x \approx 0.5$)





$\lambda(0) \approx 900$ нм $>> \xi_o$,

$\tau(T_c) = 6 \cdot 10^{-13}$ с, $R_{res} \approx 11.5$ мОм

$l(T_c) = \xi_0 \tau(T_c)\Delta/\hbar \approx 160$ нм, $l(T_c) > \xi_o$

$$R(T) = \frac{A}{T}\exp(-\frac{\Delta}{k_B T}) + R_{res}$$

$$\lambda(T) = \frac{B}{\sqrt{T}}\exp(-\frac{\Delta}{k_B T}) + \lambda(0)$$

$$\Delta \approx 2.1\, k_B T_c$$

Compton scattering

*N. Hiraoka et al., Phys. Rev. B **71**, 205106 (2005)*

Traces of CDW

0.39

0.13

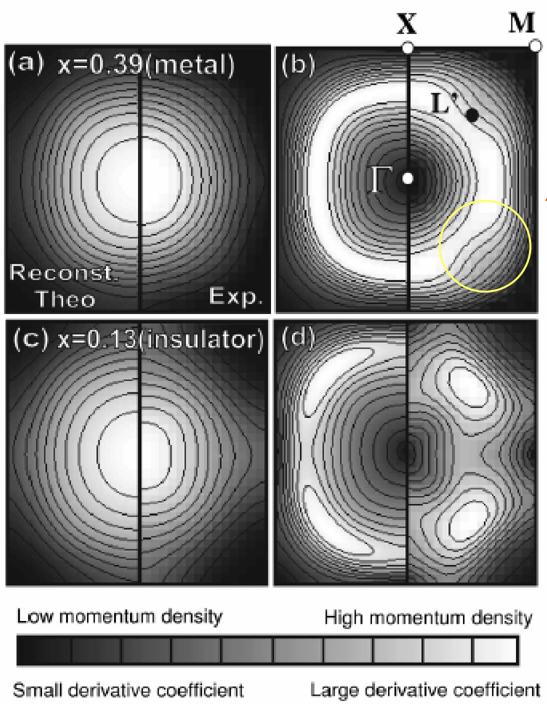


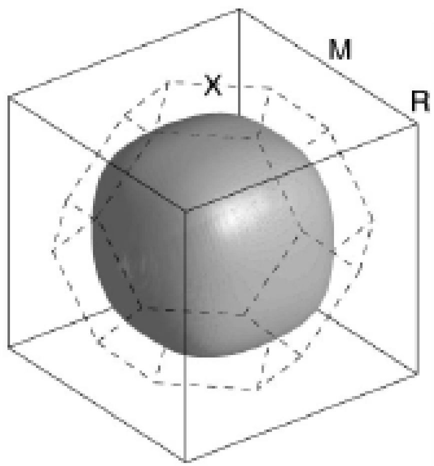
FIG. 3. Comparisons between theory and experiment for the $x=0.39$ sample [(a) momentum density and (b) derivative] and the $x=0.13$ sample [(c) momentum density and (d) derivative]. L' is the projection of L onto the (001) plane.

They are manifested as a suppressed electron density of states near the middle of diagonal of the Brillouin zone (*L* point)

Band structure

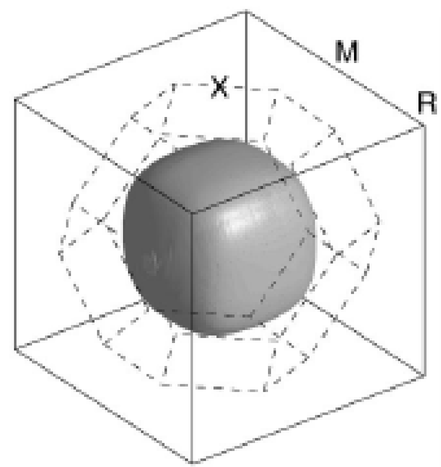
Sahrakorpi et al. PRB **61,** *7388 (2000)*

x = 0.4



$T_c \sim 30$ K

x = 0.67



$T_c \sim 5$ K

Manifestation of CDW: flat parts of the spectrum formed due to suppression of the density of states in the *L* points in the Brillouin zone

CONCLUSION II

$Ba_{1-x}K_xBiO_3$ compound is a unique object exhibiting a transition from HTSC to BCS superconductivity in the metallic phase ($x > 0.4$) when potassium doping x increases. We observe it clearly in measurements of the temperature dependences of the upper critical field $B_{c2}(T)$ and surface impedance $Z(T)$ of a series of $Ba_{1-x}K_xBiO_3$ single crystals. The change in the nature of superconductivity can be due to the special features of the electron spectrum of $Ba_{1-x}K_xBiO_3$ that are associated with the residual effect of the charge density wave and the inclusion of the high-temperature superconductivity mechanism suggested by Abrikosov

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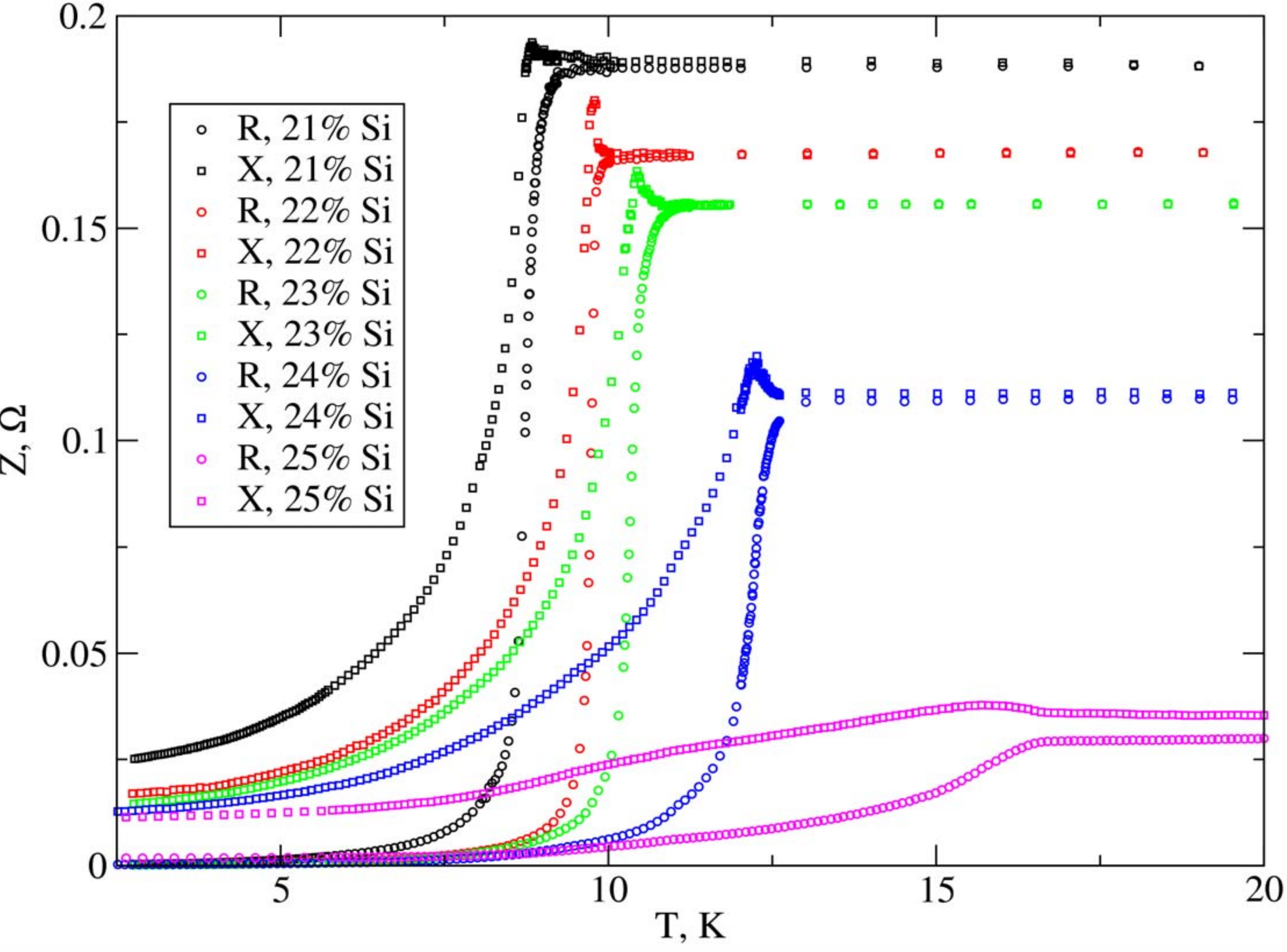
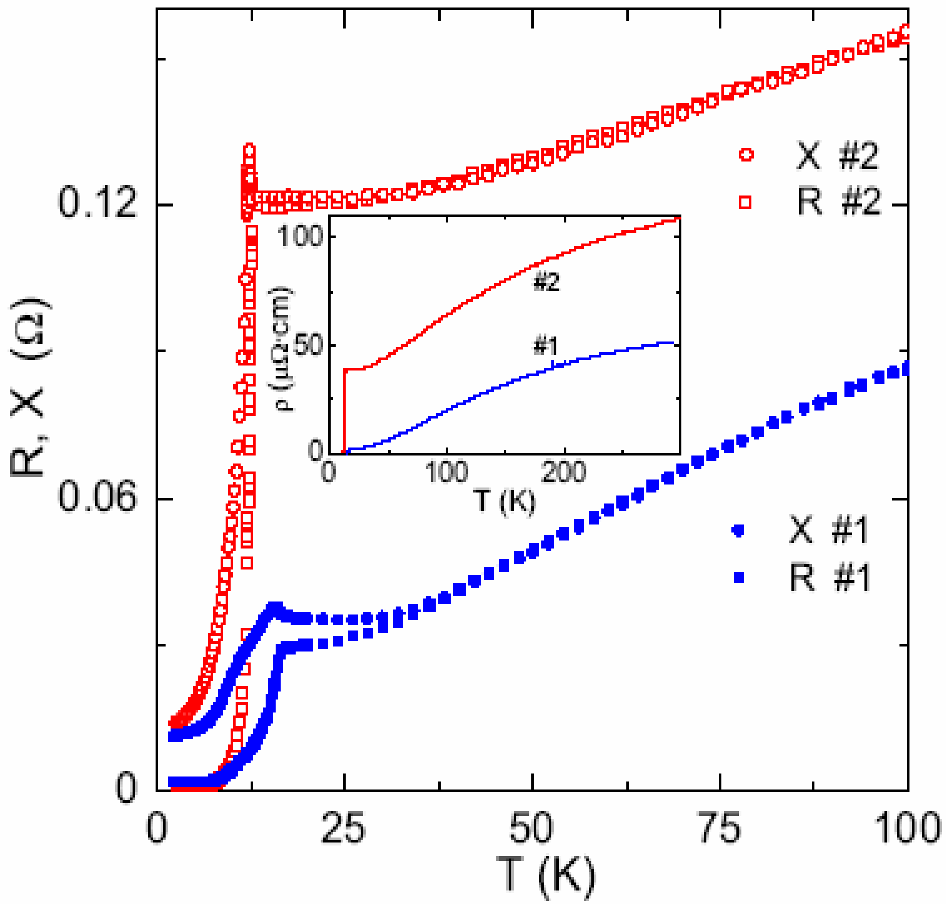
Thank you!

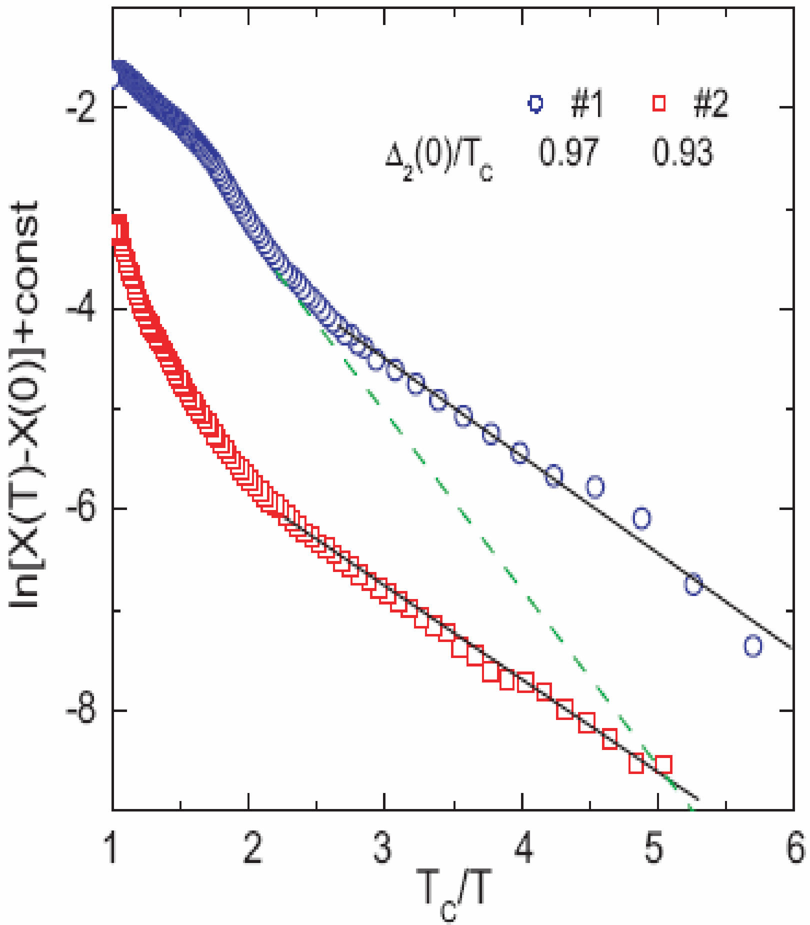
Surface resistance *R(T)* (circles) and reactance *X(T)* (squares) of V_3Si_{1-x} crystals with different silicon content

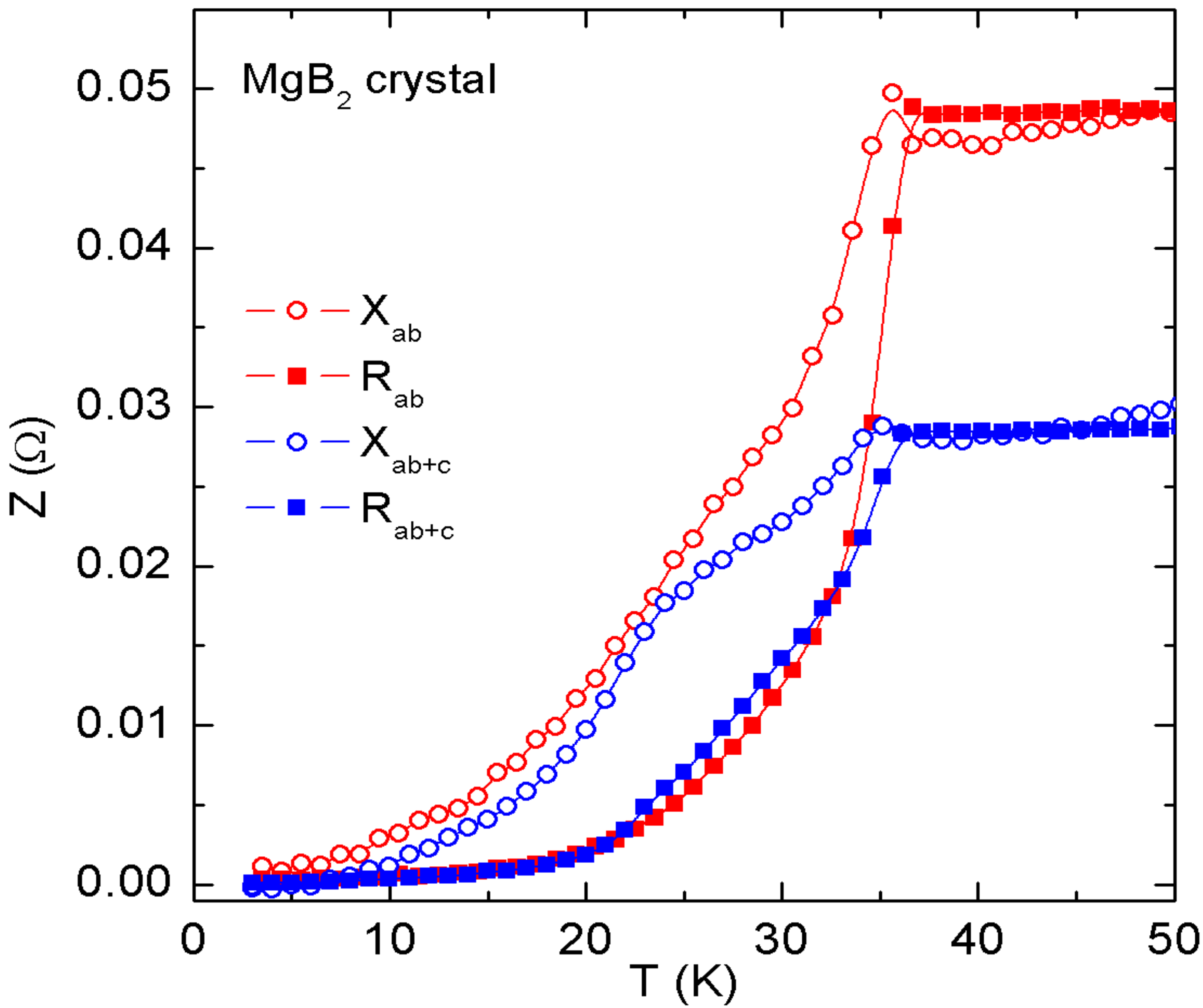


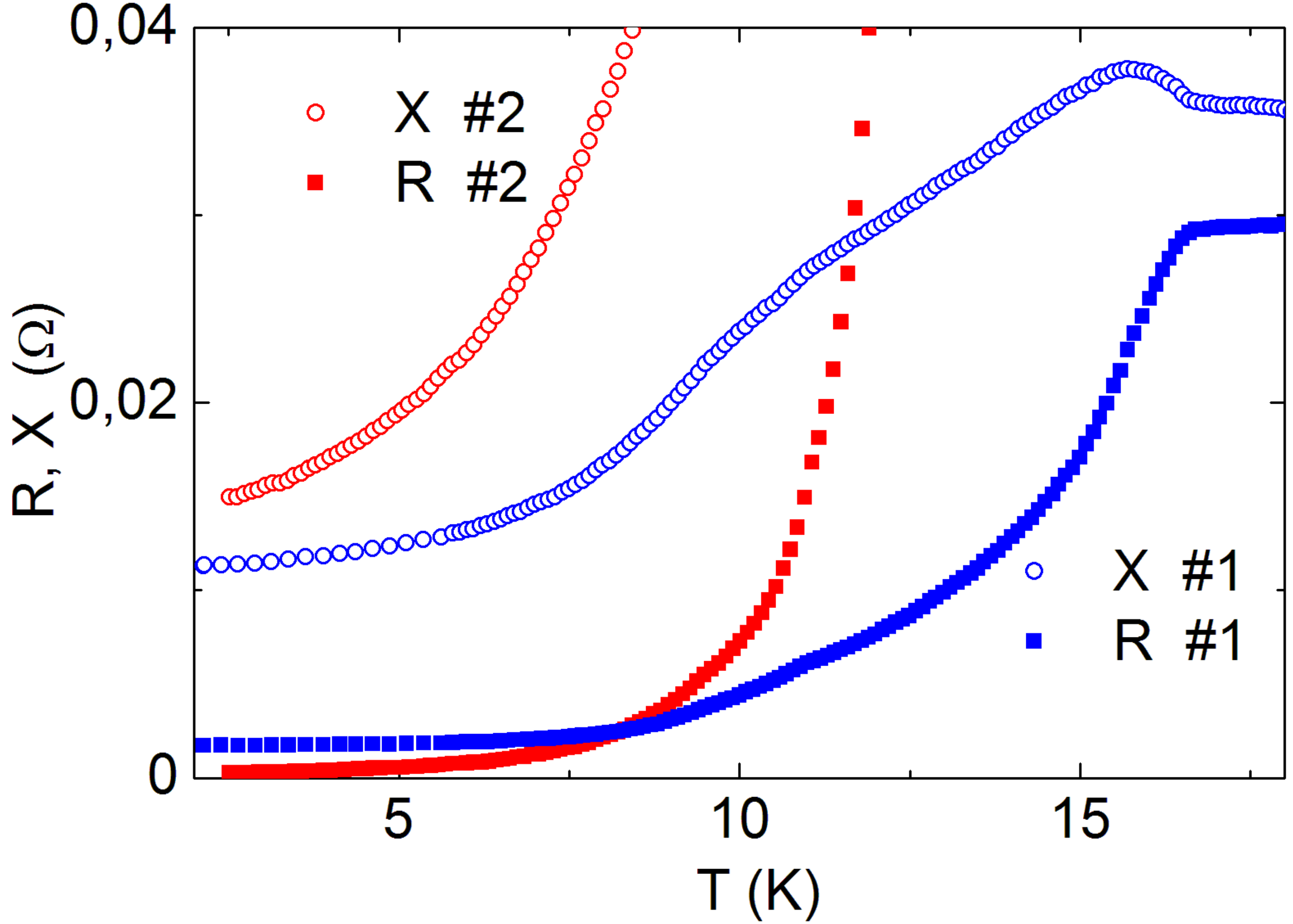
x, %	T_c, K	$\lambda(0)$, μm
21	8.9	0.33
22	9.85	0.22
23	10.5	0.19
24	12.5	0.16
25	16.6	0.15

Surface resistance and reactance of two V_3Si_{1-x} crystals # 1 (x = 0.25) and # 2 (x = 0.24)

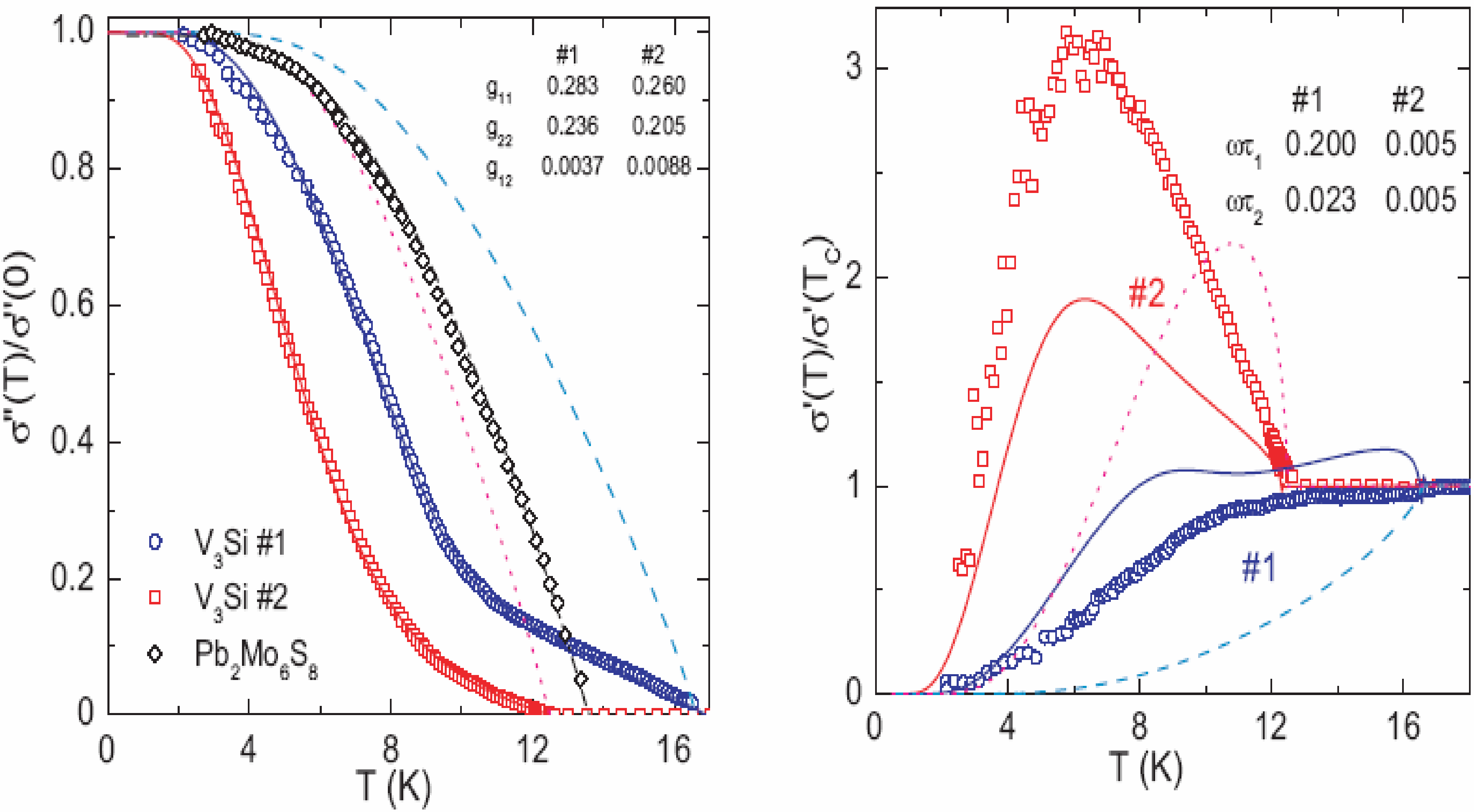




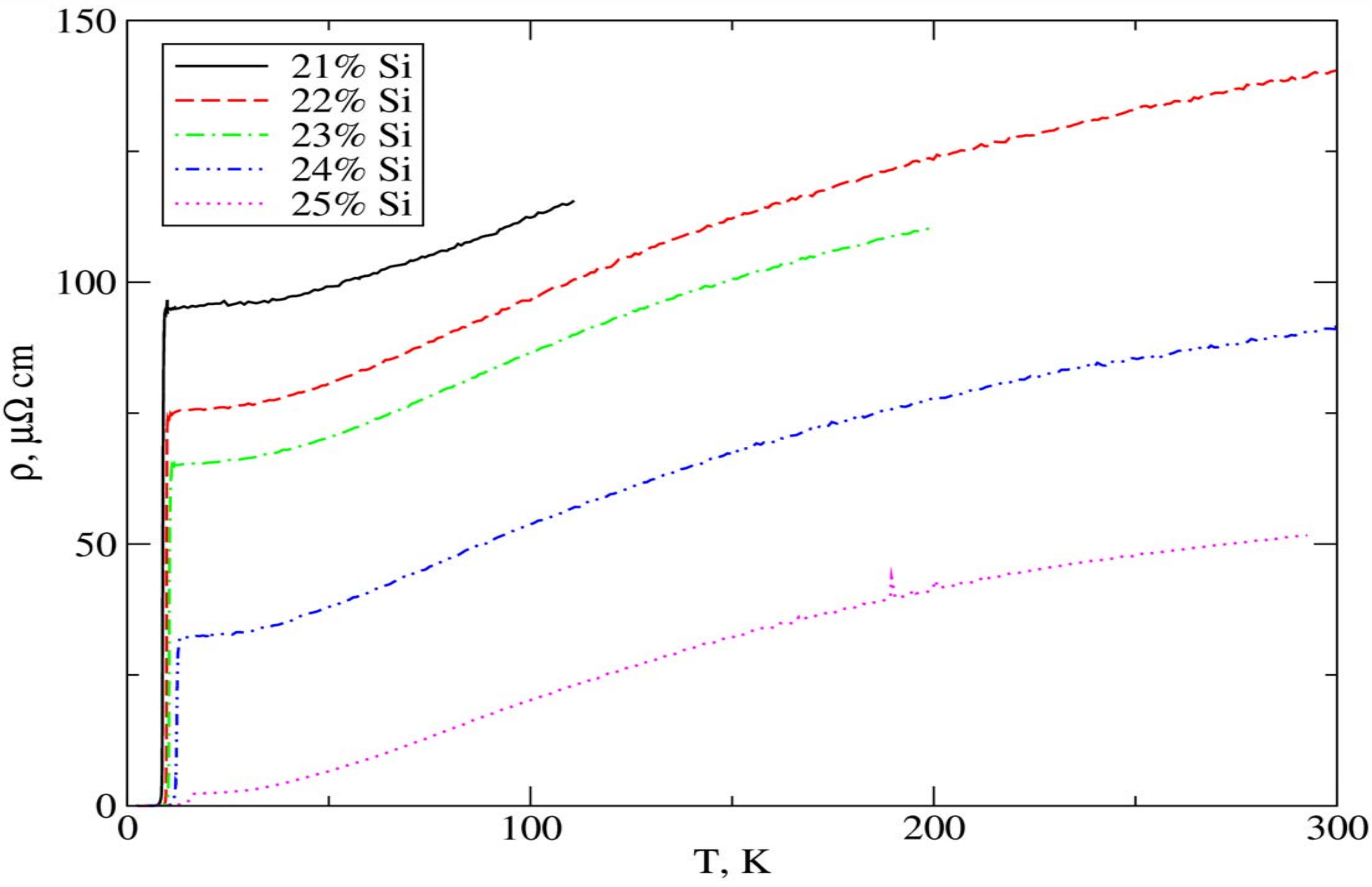

MgB2 crystal
X ab
R ab
X ab+c
R ab+c
Z (Ω)
T (K)
0.05
0.04
0.03
0.02
0.01
0.00
0
10
20
30
40
50


0,04
0,02
0
R, X (Ω)
5
10
15
T (K)
X #2
R #2
X #1
R #1

Temperature dependences of the imaginary (left) and real (right) parts of conductivity in V_3Si_{1-x} crystals # 1 ($x = 0.25$) and # 2 ($x = 0.24$) at $T < T_c$



The resistivity of V_3Si_{1-x} single crystals at $T > T_c$

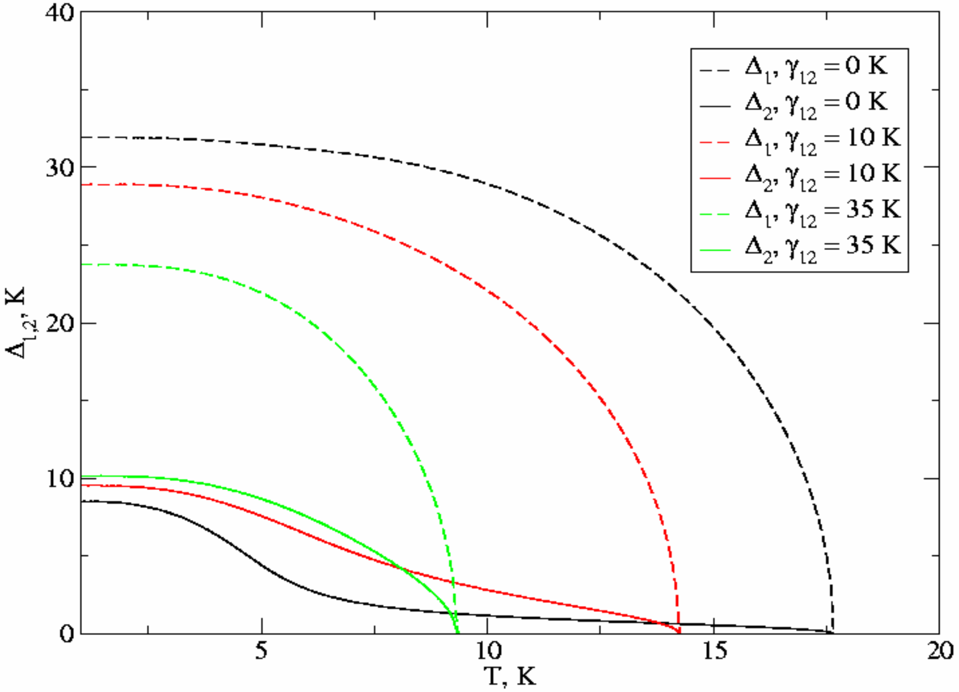


The equations for order parametres [*Golubov, Mazin. PRB* **55**, *015146 (1997)*] and the formulas for conductivity [*Nam. PR* **156**, *470 (1967)*]

$$\omega_{\alpha n} = \omega_n + \sum_\beta \frac{\omega_{\beta n}}{2Q_{\beta n}} \gamma_{\alpha n}$$

$$\Delta_{\alpha n} = \Delta_\alpha + \sum_\beta \frac{\Delta_{\beta n}}{2Q_{\beta n}} \gamma_{\alpha n}$$

$$\Delta_\alpha = 4T \sum_{\beta, n} \Lambda_{\alpha\beta} \frac{\Delta_{\beta n}}{Q_{\beta n}} arctg\left(\frac{\omega_D}{Q_{\beta n}}\right)$$

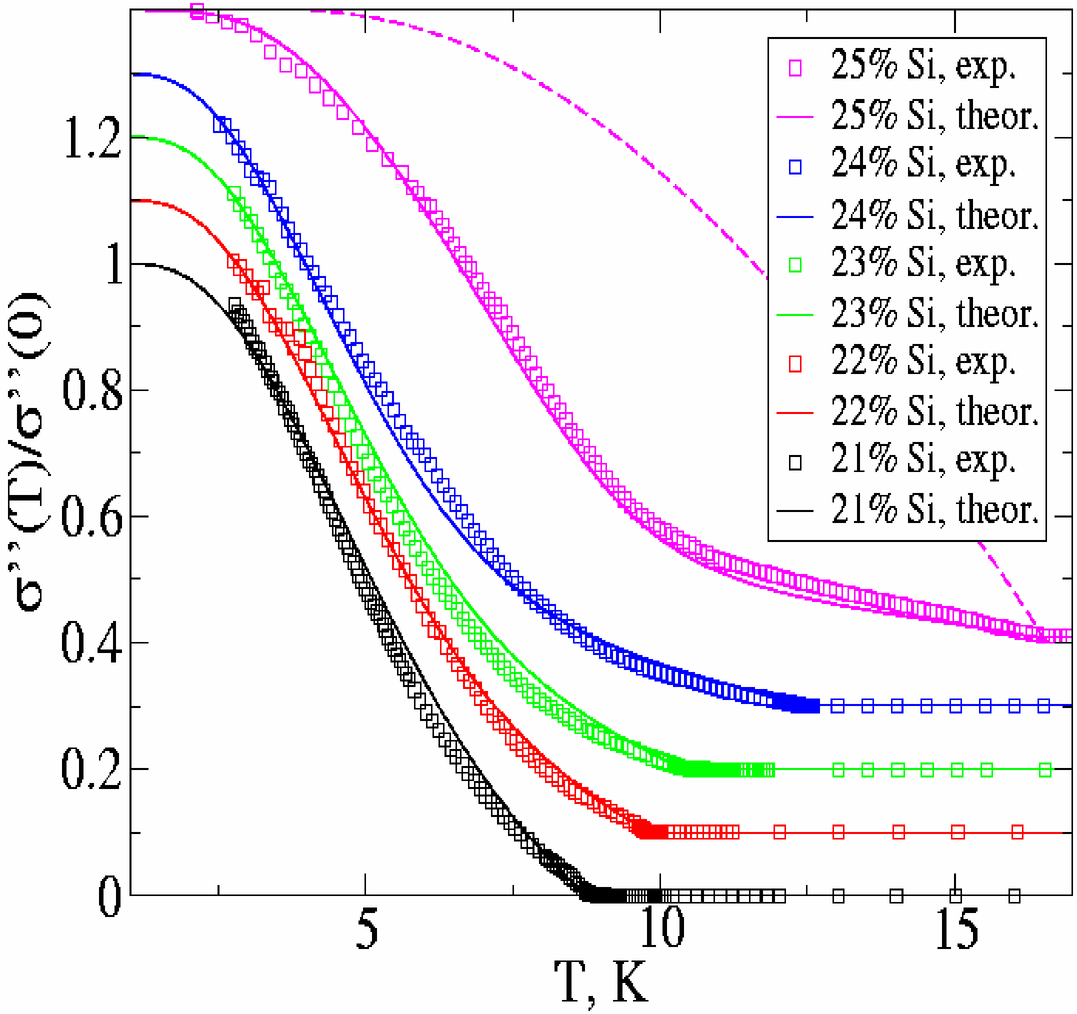


$$\frac{\sigma_\alpha(T)}{\sigma_\alpha(0)} = -\frac{i}{2}\left[\int_{\Delta_\alpha - \omega}^{\Delta_\alpha} \{I\} \tanh\left(\frac{\omega + \omega'}{2T}\right) d\omega' + \int_{\Delta_\alpha}^{\infty} \left(\{I\} \tanh\left(\frac{\omega + \omega'}{2T}\right) - \{II\} \tanh\left(\frac{\omega'}{2T}\right)\right) d\omega'\right]$$

$$\{I\} = \frac{g+1}{\varepsilon_- - i\gamma_\alpha} + \frac{g-1}{-\varepsilon_+ - i\gamma_\alpha}, \quad \{II\} = \frac{g+1}{\varepsilon_- - i\gamma_\alpha} + \frac{g-1}{\varepsilon_+ - i\gamma_\alpha}, \quad g = \frac{\omega'(\omega' + \omega) + \Delta_\alpha^2}{\sqrt{\omega'^2 - \Delta_\alpha^2}\sqrt{(\omega' + \omega)^2 - \Delta_\alpha^2}}$$

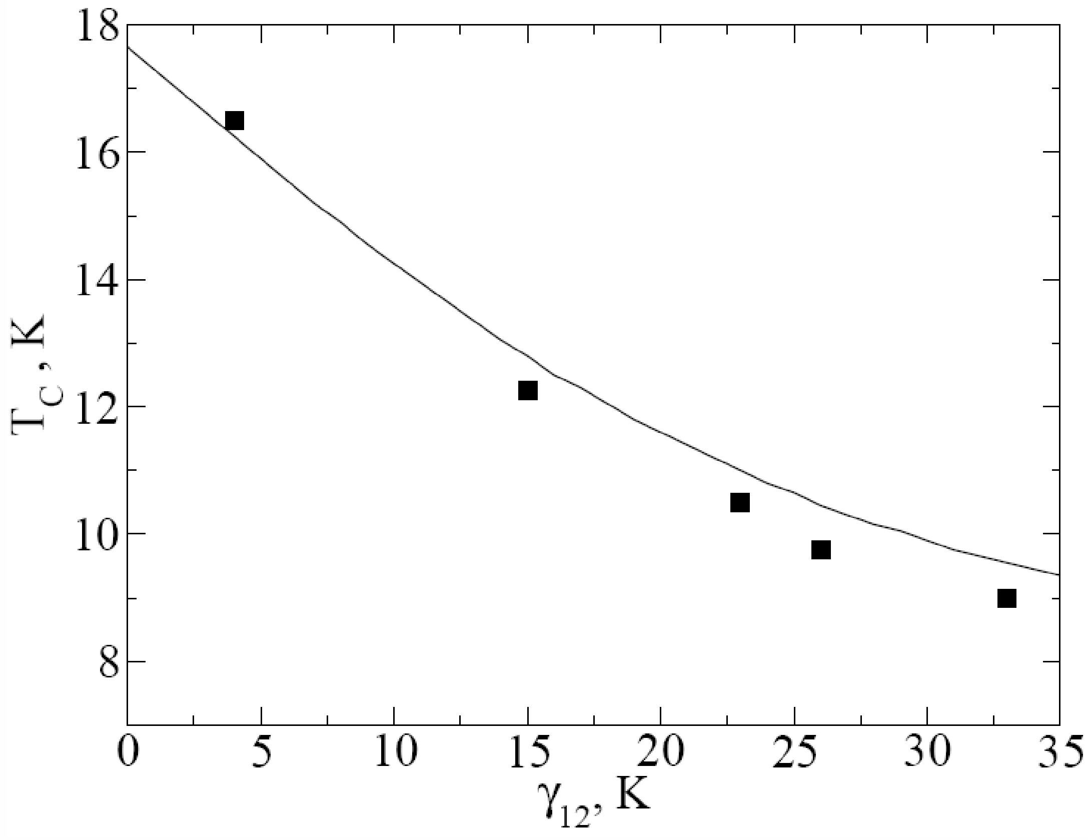
$$\varepsilon_- = \sqrt{(\omega' + \omega)^2 - \Delta_\alpha^2} - \sqrt{\omega'^2 - \Delta_\alpha^2}, \quad \varepsilon_+ = \sqrt{(\omega' + \omega)^2 - \Delta_\alpha^2} + \sqrt{\omega'^2 - \Delta_\alpha^2}$$

Temperature dependences of the imaginary parts of conductivity in V_3Si_{1-x} crystals with different silicon content



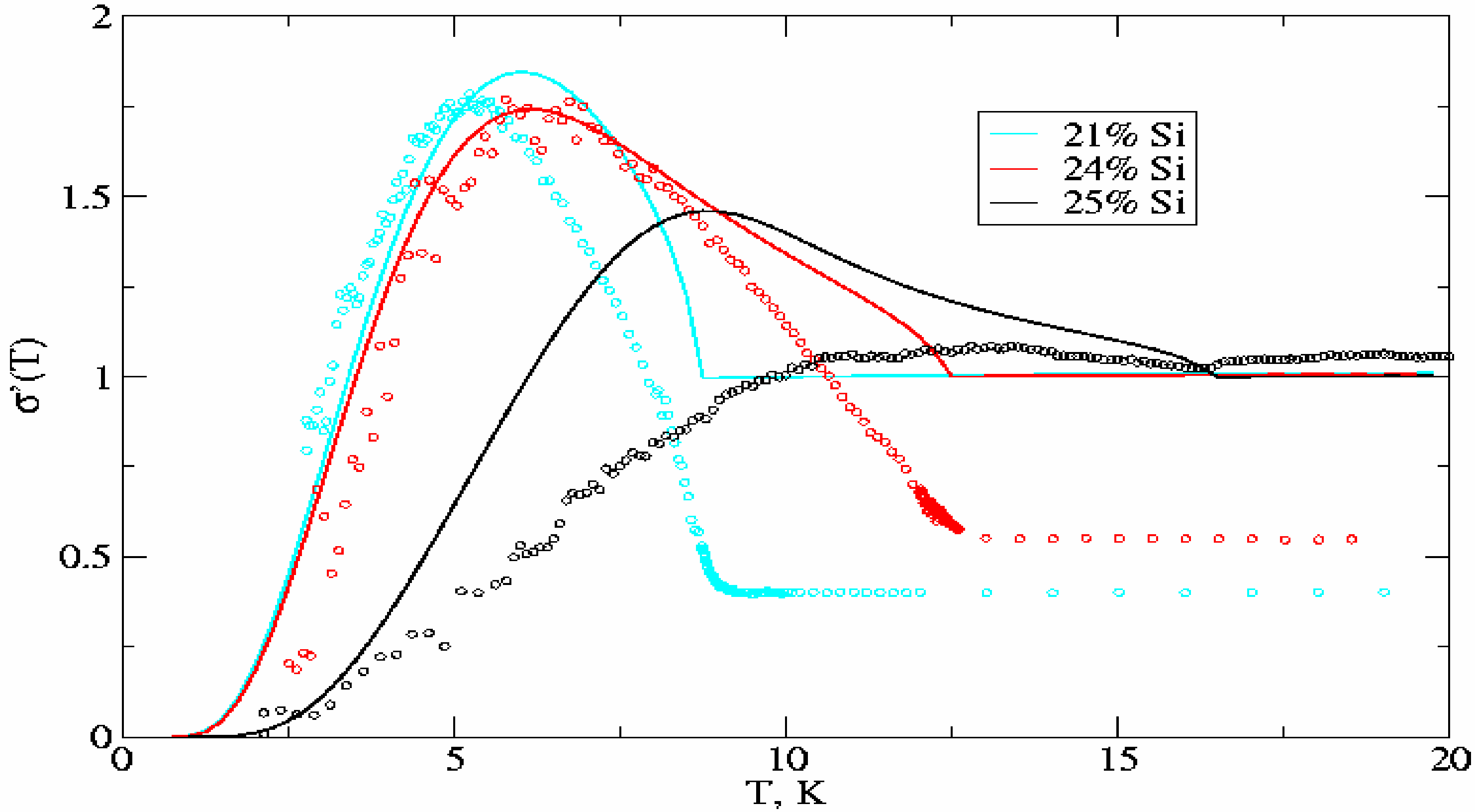
% Si	21	22	23	24	25
T_c, K	8.9	9.85	10.5	12.5	16.6
$\lambda(0)$, Å	3260	2160	1860	1640	1520
γ_{12}, K	33	26	23	15	4
Λ_{22}	0.205	0.205	0.205	0.205	0.235

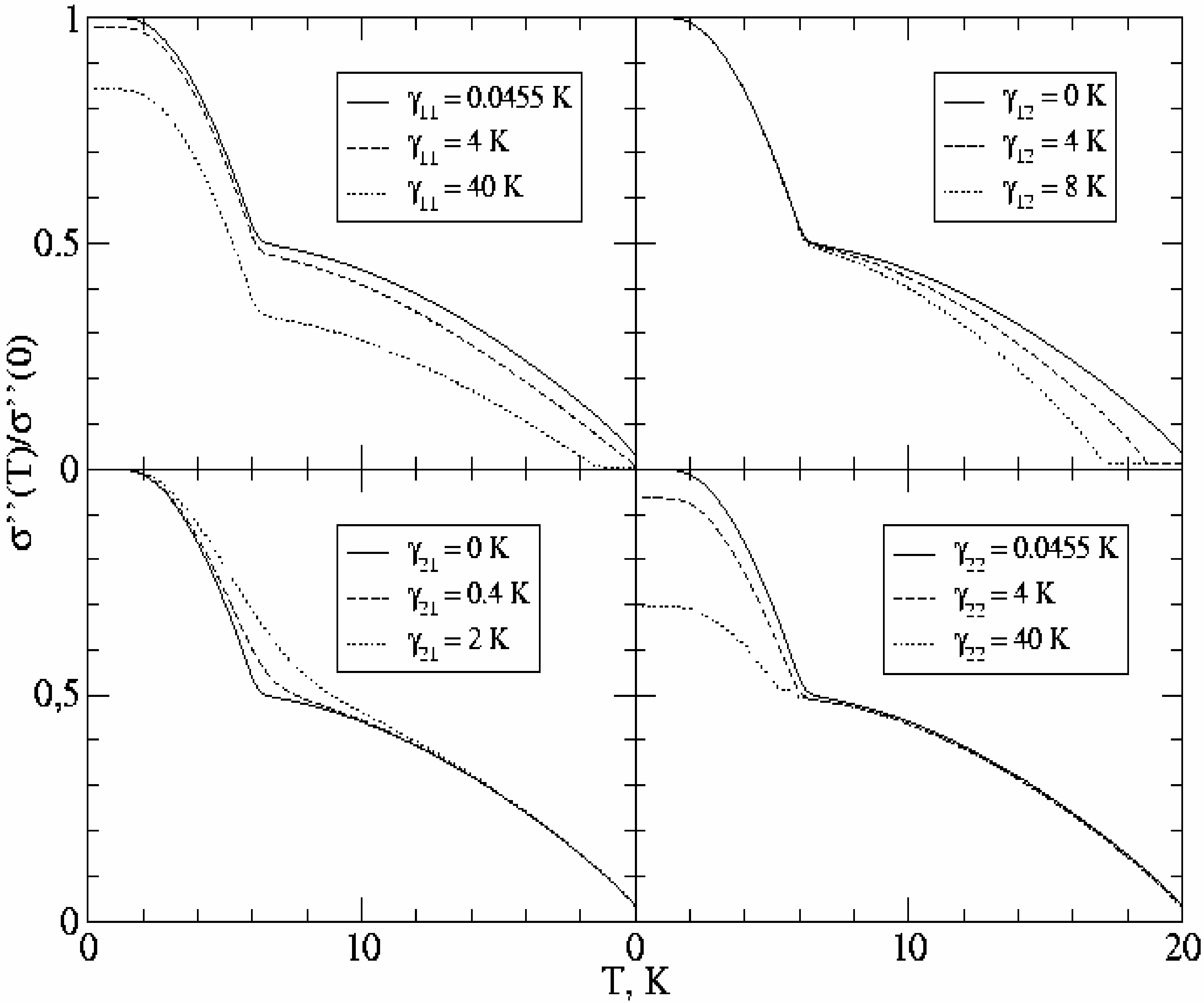
T_c *vs* interband scattering γ_{12}. Squares are experimental points obtained from the comparison of $\sigma''(T)$ curves



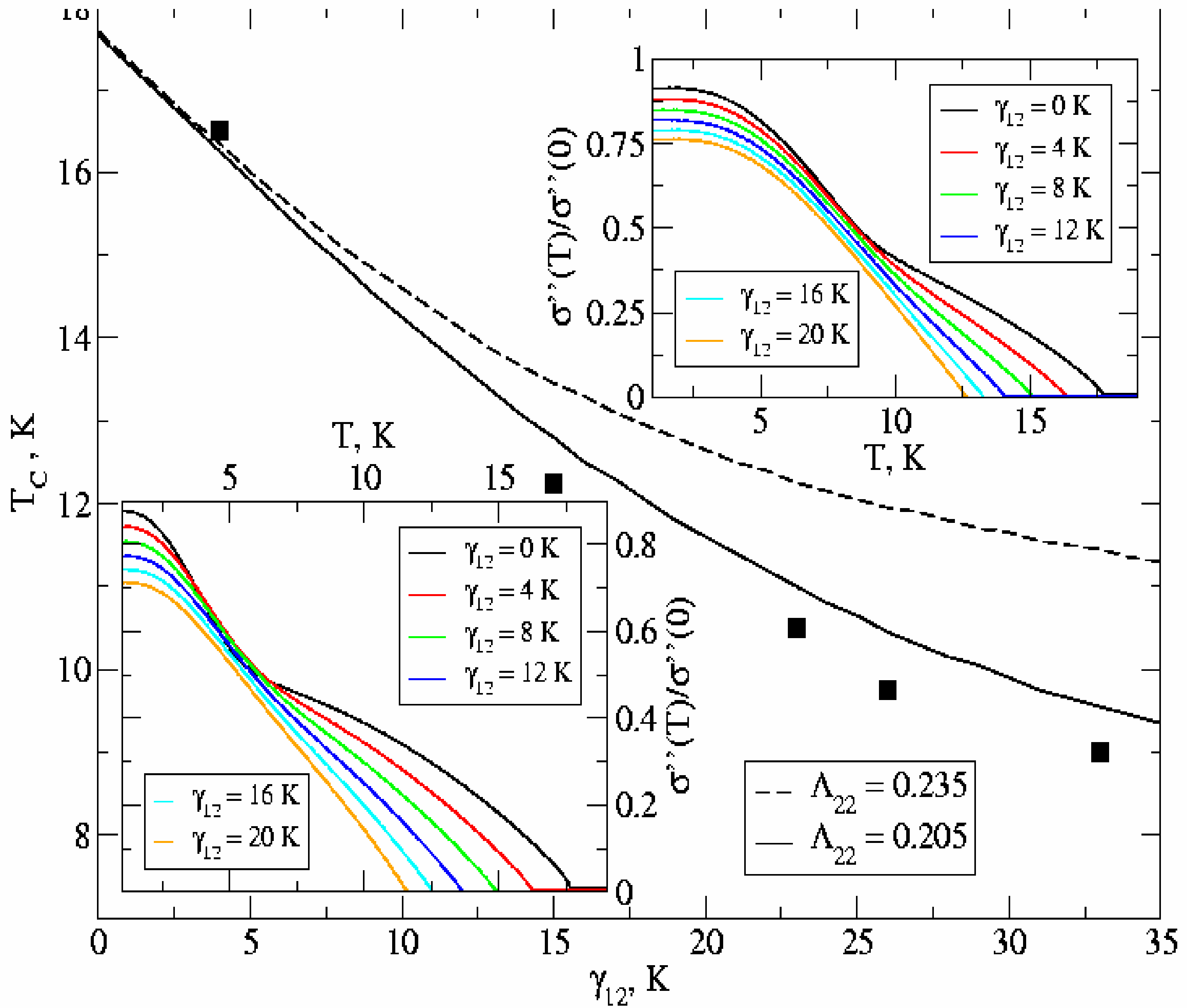
$\Lambda_{22} = 0.205,$
$\Lambda_{11} = 0.289,$
$\Lambda_{12} = 0.006,$
$\Lambda_{21} = 0.002,$
$\gamma_{11} = \gamma_{22} = 5$ K,
$n_1 = 0.07,$
$n_2 = 0.93,$
$\omega = 0.5$ K

Temperature dependences of the real parts of conductivity in V_3Si_{1-x} crystals with different silicon content



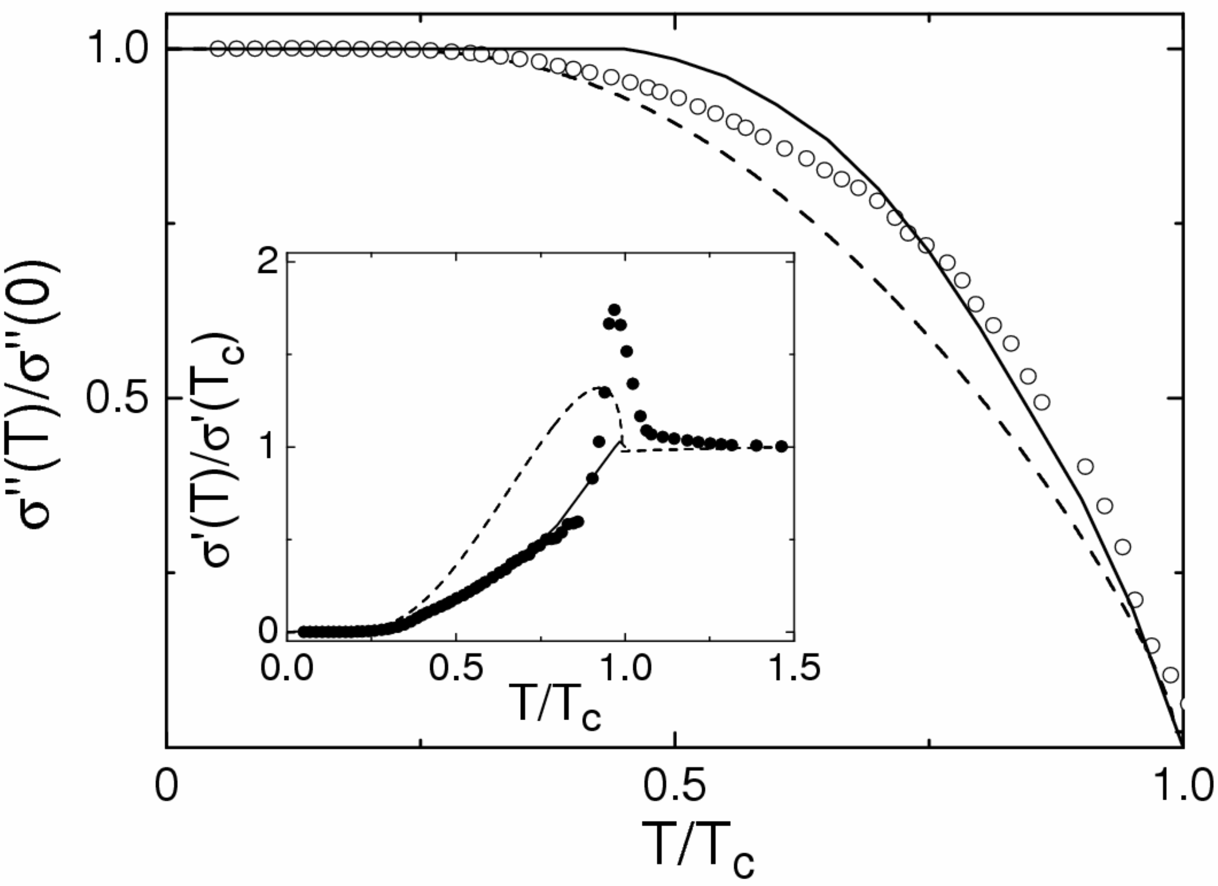


$\sigma''(T)/\sigma''(0)$
T, K
$\gamma_{11} = 0.0455$ K
$\gamma_{11} = 4$ K
$\gamma_{11} = 40$ K
$\gamma_{12} = 0$ K
$\gamma_{12} = 4$ K
$\gamma_{12} = 8$ K
$\gamma_{21} = 0$ K
$\gamma_{21} = 0.4$ K
$\gamma_{21} = 2$ K
$\gamma_{22} = 0.0455$ K
$\gamma_{22} = 4$ K
$\gamma_{22} = 40$ K



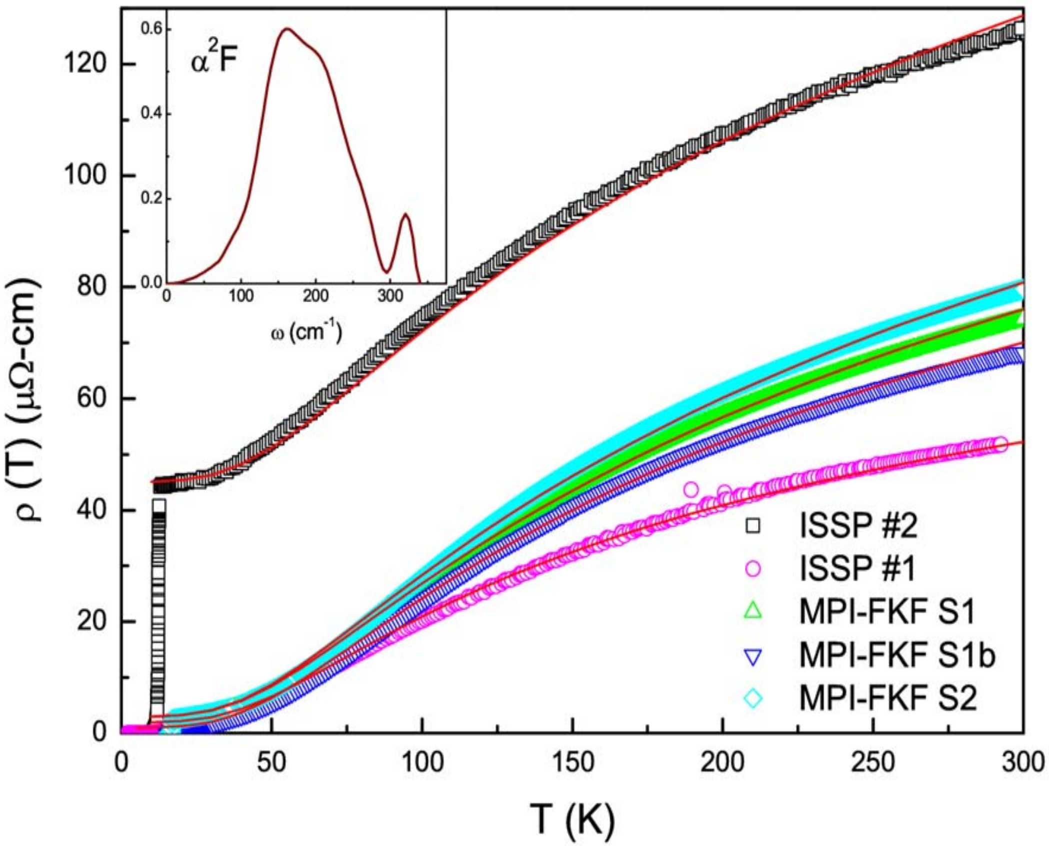
T_C , K
γ12, K
T, K
σ''(T)/σ''(0)
γ12 = 0 K
γ12 = 4 K
γ12 = 8 K
γ12 = 12 K
γ12 = 16 K
γ12 = 20 K
Λ22 = 0.235
Λ22 = 0.205

Комплексная проводимость кристалла *d* на частоте 28.2 ГГц



Точки – эксперимент. Штриховые линии – БКШ. Сплошные линии – сильная связь [*Каракозов, Максимов*. *ЖЭТФ* ***102****, 132 (1992)*]

Удельные сопротивления образцов V_3Si_{1-x} в нормальном состоянии, измеренные в разных группах (ISSP #1 и #2 – ИФТТ, MKI-FKF S1, S1b и S2 – институт им. Макса Планка в Штутгарте). Линиями показаны теоретические кривые [1]. На вставке - транспортная функция Элиашберга [2], использовавшаяся в расчетах

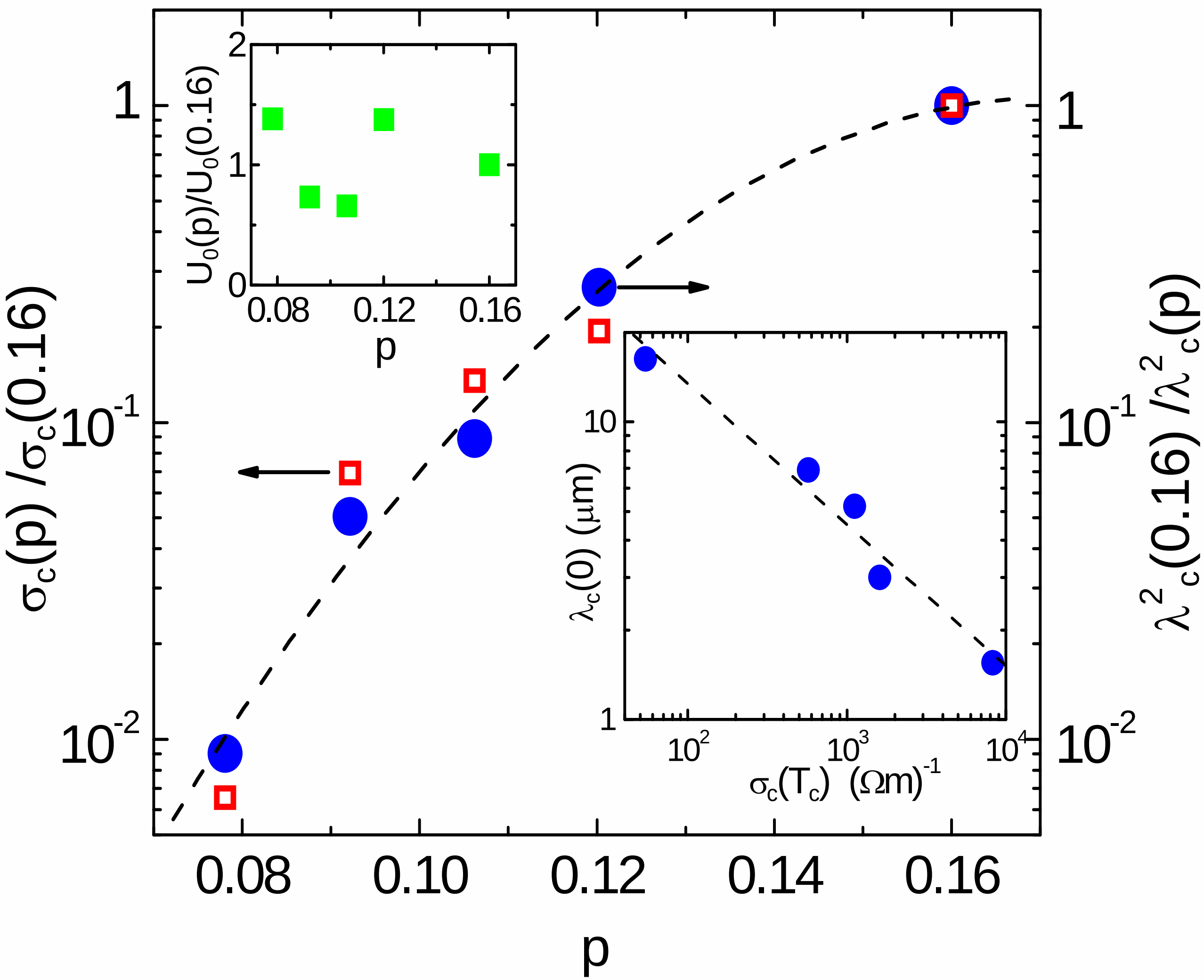


[1] *Dolgov. private communications*

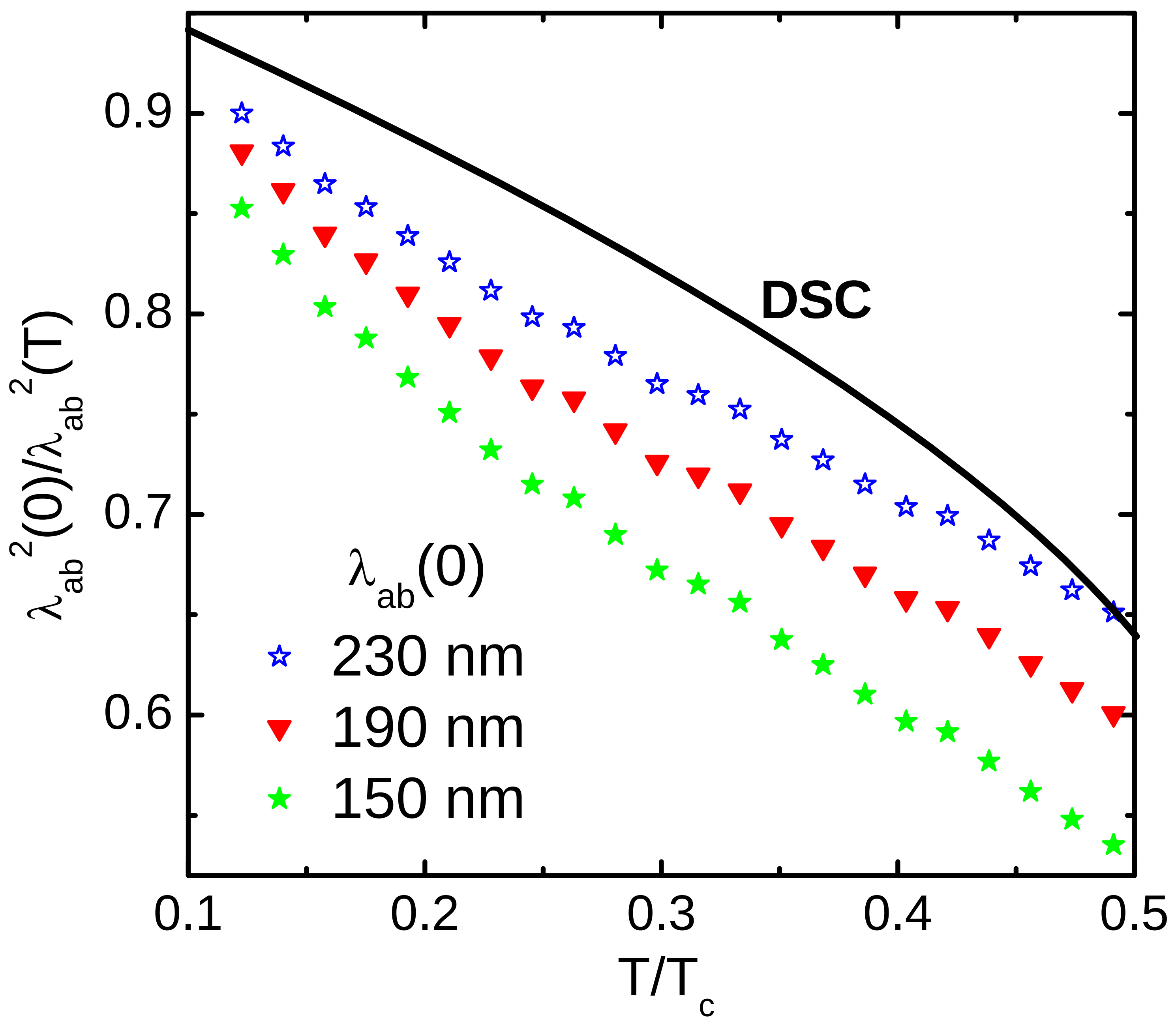
[2] *Kihlstrom. Phys. Rev. B* ***32,*** *2891 (1985)*

$$1/\lambda_c^2(0, p) = U_0(p)\sigma_c(T_c, p)$$

Kim, Carbotte et al. PRB ***65****, 064502 (2002)*

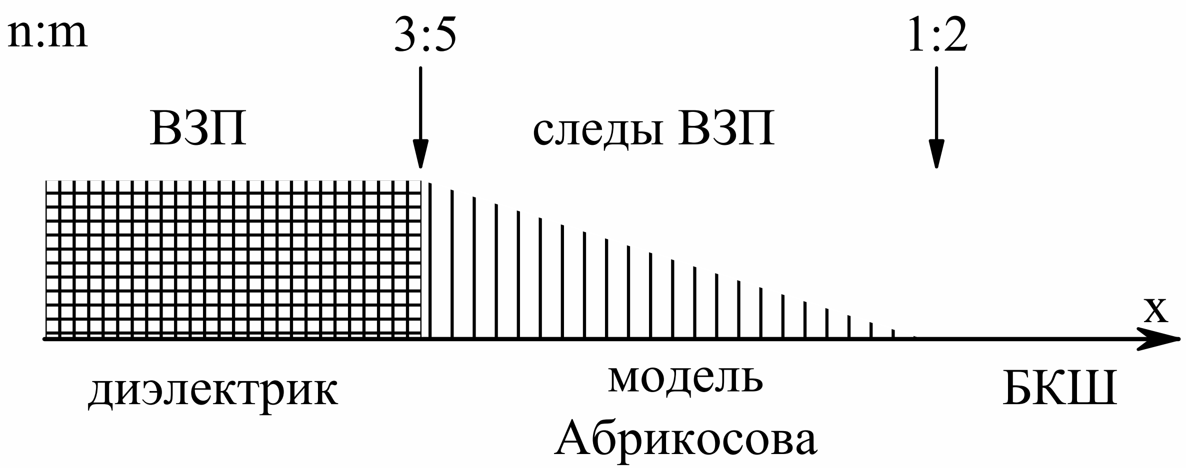


DDW-псевдощель практически не влияет на зависимость $\lambda_c(0, p)$. Поведение $\lambda_c(0, p)$ определяется сильным уменьшением интеграла перекрытия $t_\perp(p) \propto \sigma_c(T_c,p)$ с уменьшением p в $YBa_2Cu_3O_{7-x}$



DSC
$\lambda_{ab}(0)$
230 nm
190 nm
150 nm
0.9
0.8
0.7
0.6
0.1
0.2
0.3
0.4
0.5
$\lambda_{ab}^2(0)/\lambda_{ab}^2(T)$
T/T_c

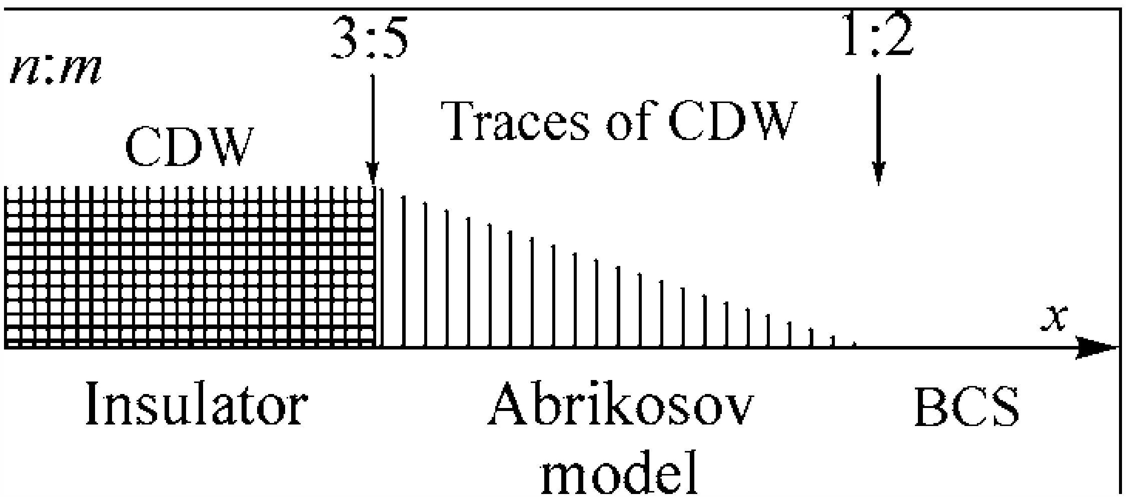
Схема предполагаемой фазовой диаграммы $Ba_{1-x}K_xBiO_3$



Согласно гипотезе [*Клинкова. СФХТ* ***7****, 418 (1994)*] величина ***x*** принимает значения n:m = Ba:Bi.
3:5 => ***x***=0.4; 1:2 => ***x***=0.5

x < 0.4: дальний порядок в расположении ионов Bi^{5+}, ВЗП;
0.4 < ***x*** < 0.5: ближнее упорядочение ионов Bi, «следы» ВЗП;
x > 0.5: разрушение ближнего порядка, сжатие поверхности Ферми

Hypothetical phase diagram of $Ba_{1-x}K_xBiO_3$



The Ba-to-Bi content ratios $n : m$ that correspond to presumed phase boundaries are indicated