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Comparison of the optically measured vaporization energy by ultrafast laser spectroscopy and condensation energy determined from specific heat measurements in superconducting cuprates

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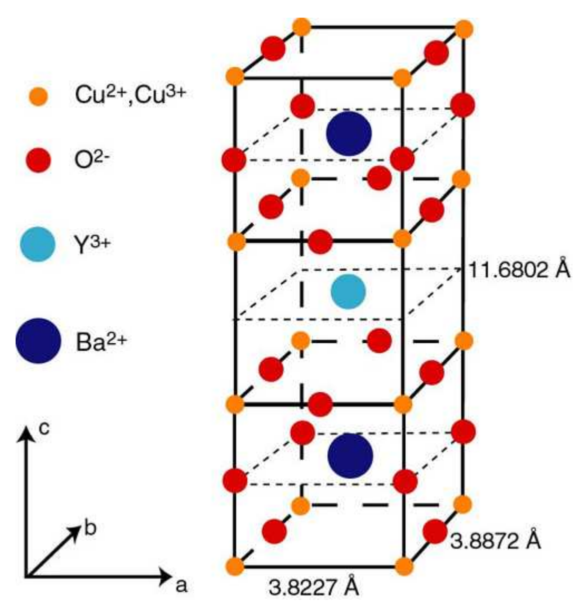
Motivation

Our goal was determination of the energy needed to transform the superconducting state into the normal state (i. e. vaporizate the condensate) and compare with calculated condensation energy in$YBa_2Cu_3O_{7-d}$

Physical properties of $YBa_2Cu_3O_{7-\delta}$

$YBa_2Cu_3O_{7-\delta}$ (YBCO) is high-T_c supercinducting cuprate with layered perovskite and highly anisotropic structure.An essential structural element is one or more copper oxide plane (CuO_2), which is thought to contribute to the superconducting properties. Changing the oxygen stoichometry in charge reservoirs planes (located above and below CuO_2 planes), leads to change in electronic properties (change in T_c).

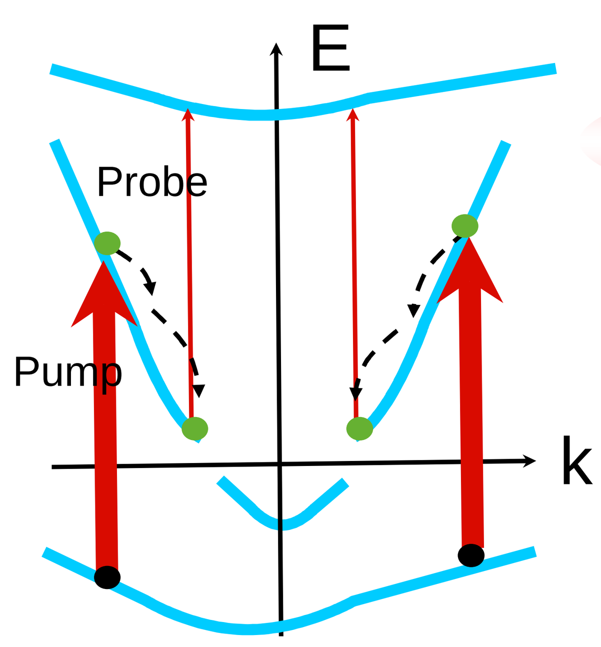


Schematic structure of $YBa_2Cu_3O_{7-\delta}$. Unit cell consists of two CuO_2 planes with Y ion in between. Charge reservoirs planes are CuO planes.

Sample preparation

We annealed YBCO crystals in flowing oxygen at high temperatures from 400 to 900 °C for certain time and then quenching them by rapidly taking away from the owen. In this way we prepared samples with critical temperatures ranging from 60 to 90 K. Critical temperature was determined from magnetization measurements. At the end the surface was cleaved and all laser measurements have been performed on [a,b] plane.

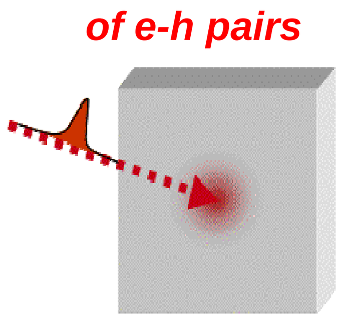
How we can determine vaporization energy?



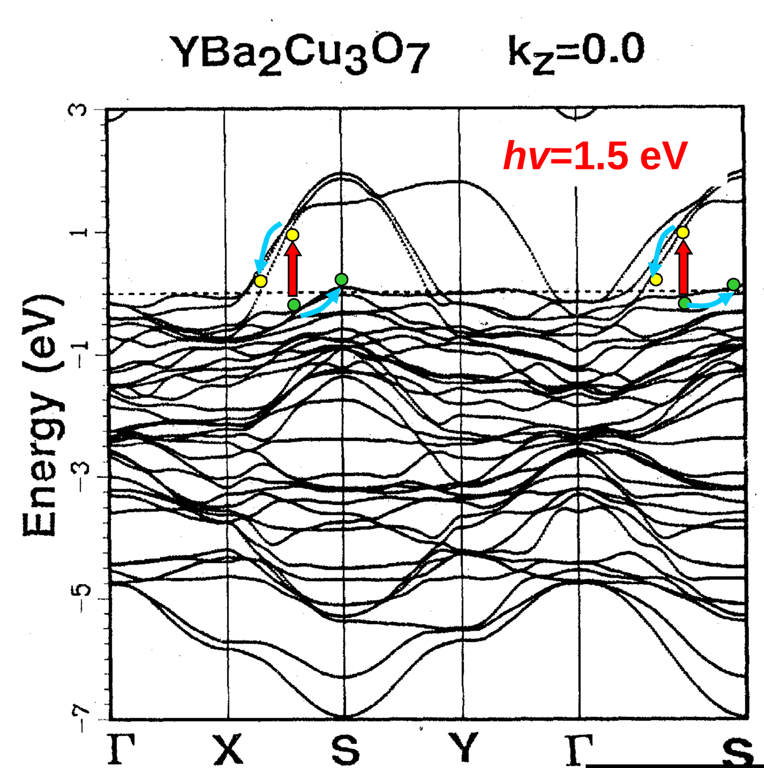
Schematic of pump-probe technique. With the first beam - pump we excite the sample and with the second beam we probe the changes in reflectivity (transmission) as a function of time delay after the first pulse.

For studying quasiparticle relaxation dynamics we used femtosecond time-resolved pump-probe technique. The wavelength of the laser pulses was λ=800 nm (~1.5 eV) and their pulselength was ~ 50 ps. The intensity ration of pump and probe beams was typically 100. To avoid any possible coherent effects, these two beams were perpendiculary polarized.

1. *Excitation of e-h pairs*

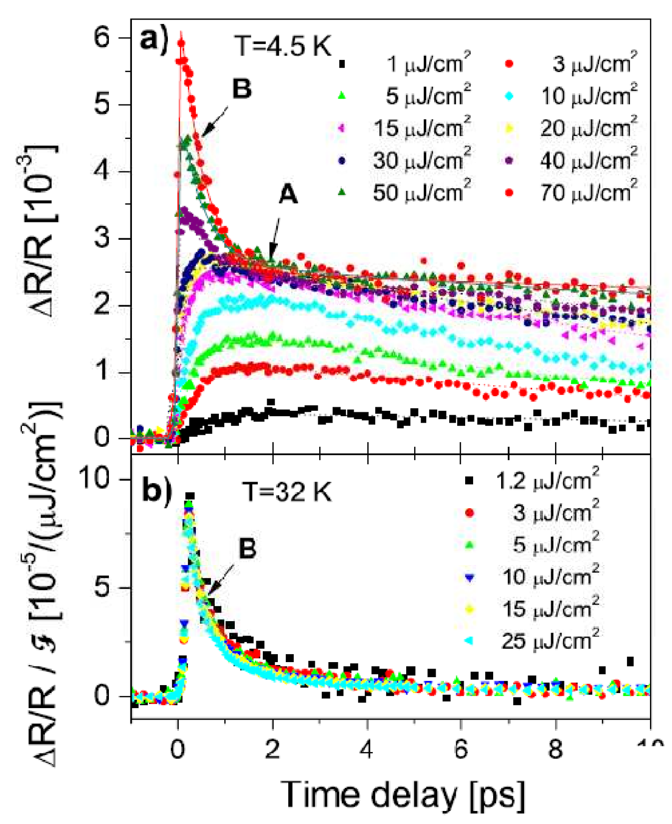


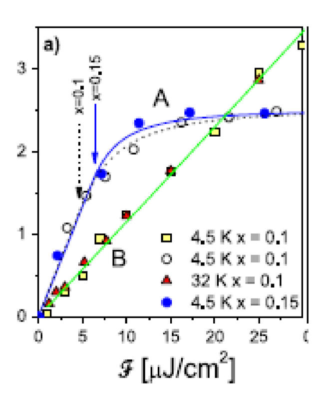
2. *Intraband e-e cattering and thermalization with optic phonons* τ *~10 – 40 fs*



Representation for the energy band structure in $YBa_2Cu_3O_{7-d}$ and excitation and relaxation processes.

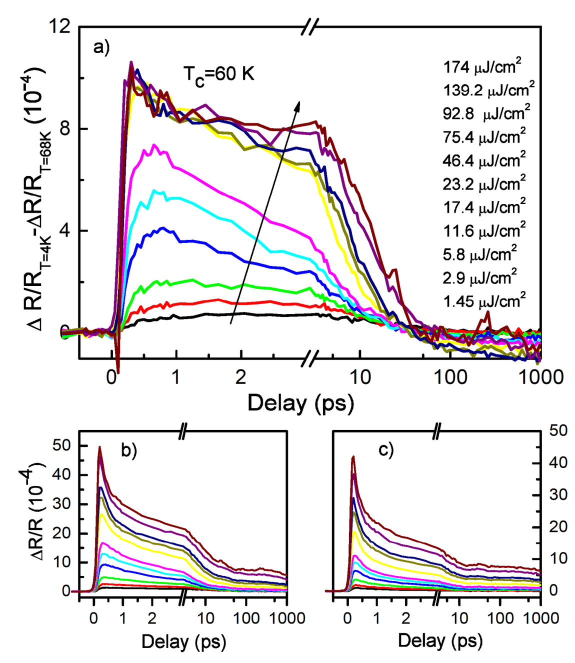
Measurements and results

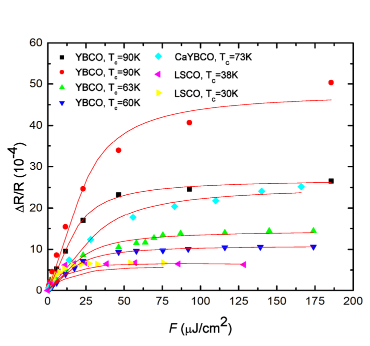




By using mathematical model we fit ΔR/R=f(F) and determine fluence threshold. Taking into account geometric factors related to the laser beam profile and optical absorption length, we can calculate vaporization energy U_v.

First measurements in $La_{2-x}Sr_xCuO_4$ showed that as we increase laser fluence, the amplitude of the signal first increases and then starts to saturate for certain value of the laser fluence.





We observed fluence saturation also in $YBa_2Cu_3O_{7-d}$

Conclusions

By comparing measured vaporization energy and thermodinamically determined condensation energy, we found that certain amount of energy is stored by the glue boson.

Copper oxides superconductors (cuprates)

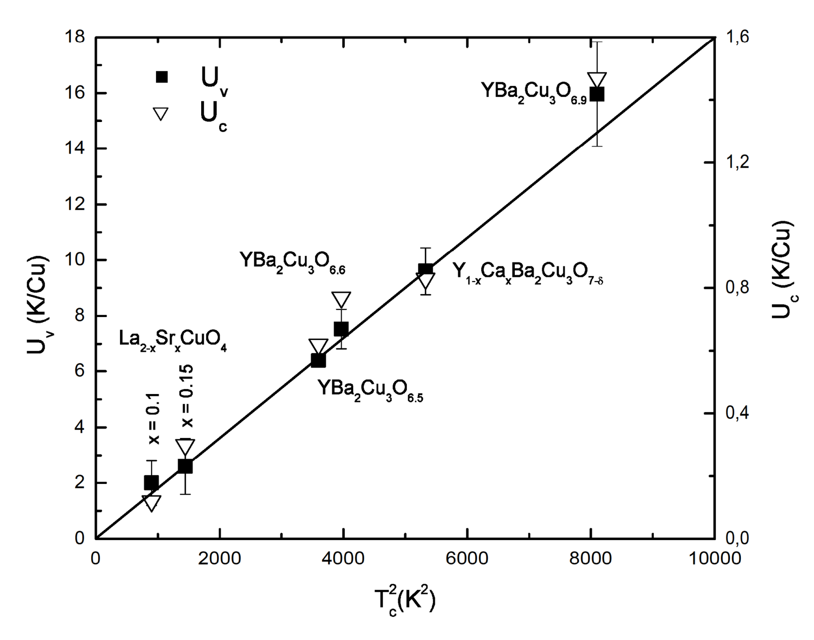
Iron-based superconductors (pnictides)

Conventional superconductors

Charge-density waves systems

Material	T_c (K)	U_v	U_c	U_v/U_c
$La_{2-x}Sr_xCuO_4$ x =0.1	30	2±0.8 K/Cu	0.12K/Cu	16.7
$La_{2-x}Sr_xCuO_4$ x=0.15	38	2.6±1 K/Cu	0.3 K/Cu	8.5
$YBa_2Cu_3O_7$	92	15.9±1.9 K/Cu	1.5 K/Cu	10.6
$YBa_2Cu_3O_{6.6}$	63	7.5±0.7 K/Cu	0.77K/Cu	9.7
$YBa_2Cu_3O_{6.5}$	60	6.4±0.2 K/Cu	0.62K/Cu	10.3
$Y_{1-x}Ca_xBa_2Cu_3O_{7-d}$ x=0.22, d=0.5	75	9.2±1 K/Cu	0.83K/Cu	11.6
$SmFeAsO_{0.8}F_{0.2}$	49.5	1.8 K/Fe	1.7K/Fe	~1
NbN	16	0.24 K/Nb	0.14K/Nb	~1
$TbTe_3$	315	52 K/Tb	40.6K/Tb	1.3
$(TaSe_4)_2I$	260	7.22±4.2 K/Ta	16.5±7.22K/Ta	~1
$K_{0.3}MoO_3$	180	4.2 K/Mo	4.7K/Mo	~1

Ratio U_v/U_c for cuprates is quite large compared to other superconductors and CDWs!



Vaporization vs condensation energy as a function of T_c^2 for various doping level of $YBa_2Cu_3O_{7-d}$. Both, vaporization and condensation energy appear to follow square power law dependence on T_c.