Theory of light-enhanced superconductivity

arXiv:1505.07575

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Light-induced superconductivity?

“Possible light-induced superconductivity in K3C60 at high temperature”
M. Mitrano et al., Nature 530, 461 (2016)
How to enhance boson-mediated SC?

- BCS theory – plain vanilla SC (weak coupling)

\[ \Delta \approx 2\hbar \Omega_c \exp\left(-\frac{1}{V_0 N(E_F)}\right) \]

- effective attraction \( V_0 \sim g^2/(\hbar \Omega) \)
- e-boson coupling \( g \)
- boson frequency \( \Omega \)
- electronic DOS \( N(E_F) \)

Migdal-Eliashberg theory
boson-mediated pairing
Nonlinear phononics

"Nonlinear phononics"
M. Först et al., Nature Physics 7, 854 (2011)
A. Subedi, A. Cavalleri, A. Georges, PRB 89, 220301R (2014) M. Knap et al., arXiv:1511.07874

Rectification of a second (Raman) phonon via coherent driving of a first (IR) phonon

Enhancement of SC via enhanced DOS at Fermi energy?
Model and Method

\[ \mathcal{H} = \sum_{k\sigma} \epsilon(k, t)c_{k\sigma}^\dagger c_{k\sigma} + \sum_{q, \gamma} \Omega_\gamma b_{q, \gamma}^\dagger b_{q, \gamma} - \sum_{q, \gamma, \sigma} g_{\gamma} c_{k+q\sigma}^\dagger c_{k\sigma} \left( b_{q, \gamma} + b_{-q, \gamma}^\dagger \right) \]

electrons (2D) + phonons + el-ph coupling (Holstein)

Migdal-Eliashberg, nonequilibrium Keldysh Green functions:

Normal

\[ \mathcal{G} = \mathcal{G} + \mathcal{G}^\dagger \]

Anomalous

\[ \mathcal{G}^+ = \mathcal{G} \]

order parameter \( \Delta \), condensate dynamics

el-ph single-particle scattering

Max Planck Institute for the Structure and Dynamics of Matter
Hopping ramp

Enhancement of SC via enhanced DOS at Fermi energy?
Enhancement of SC strongly depends on initial thermal state.
Enhancement during ramp

Order parameter enhancement $\sim \Delta_0$ determines time scale on which SC can be induced by quasistatic modification of effective pairing strength!
Superconductor evolution

![Graph showing the evolution of a superconductor with time at different temperatures and relaxation times.](image)

- τ = 3 fs
- τ = 100 fs

Temperatures:
- 96 K
- 130 K
- 133 K

Time in [fs]:
- 0 to 300
Dissipation of energy to phonons helps SC enhancement for fast ramps.

Dissipation important for approach to final thermal state.

\[
\Delta [\text{eV}] \quad \text{time [fs]}
\]

- \(\tau = 3\) fs
- \(\tau = 100\) fs

Dashed: no dissipation (BCS only)
Summary  

• Light-enhanced superconductivity via nonlinear phononics: order parameter versus dissipative dynamics

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