The anomalies of the quasiparticle current in superconducting multiple tunnelling junctions.

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We have developed a theory of anomalous sub-gap currents in small gap superconducting multiple tunnelling junctions based on the solution of the coupled kinetic equations for interacting quasiparticles and phonons including also contributions from tunnelling and backtunnelling terms. Multiple tunnelling small gap structures are generally considered as an important contender for future single IR and optical photon detectors for astronomical applications. Recently sub-gap currents in these structures were shown to be larger than could be explained by thermal excitation with important implications for their performance.

The study of sub-gap structures in the I-V characteristics of superconducting tunnelling junctions has a long history. Specific sub-gap structures at voltages $V = 2\Delta / en$ (n is integer) have previously been attributed to the following mechanisms: multiple-particle tunnelling, photon-assisted tunnelling due to coupling to ac-Josephson current, multiple Andreev reflection.

In this paper we show that there exists a new class of phenomena resulting in a wealth of sub-gap current structure in a special type of junctions, namely multiple tunnelling small gap structures. The smallness of the gap results in a relatively slow inelastic phonon scattering rate $\tau_S^{-1} \propto \Delta^3$ in comparison with the tunnelling rate Γ_t , which normally does not contain any significant dependence on Δ. As a result, each time the quasiparticle tunnels it emerges in the other electrode with extra energy eV above the superconducting gap. If the quasiparticle survives at this energy level sufficiently long then the backtunnelling process recycles the quasiparticle to the initial electrode at an energy of $2eV$, and so on. Finally after $\lfloor 2\Delta / eV \rfloor + 1$ (where symbol [...] stands for the integer part) tunnelling events the quasiparticle can gain excess energy above the threshold of 3Δ . From there it can relax down to the superconducting gap with emission of an energetic ($\hbar\Omega$? 2Δ) phonon, triggering the multiplication of quasiparticle numbers due to phonon breaking of Cooper pairs. This process contributes to the formation of a strongly non-equilibrium stationary distribution of quasiparticles and phonons which at low bath temperatures is characterised by occupation numbers far exceeding that of thermal equilibrium. In addition each time the quasiparticle reaches the 3Δ threshold after n tunnelling events, that is at voltages of $V = 2\Delta / en$, a step in the I-V characteristic will appear as with the increase of voltage above this value a larger fraction of the quasiparticles from the initial distribution is able to reach the threshold.

We discuss the main features of stationary non-equilibrium distribution of quasiparticles and phonons and show that the shape of steps on I-V curves and their magnitudes as well as their dependence on bath temperature depend on major junction parameters, including rates of quasiparticle tunnelling, recombination, residual losses and phonon escape from the junction into substrate.

We discuss and compare the main predictions of the theory to the available experimental data.