Differential shot noise and Fano factor in mesoscopic junctions with inhomogeneous superconductors

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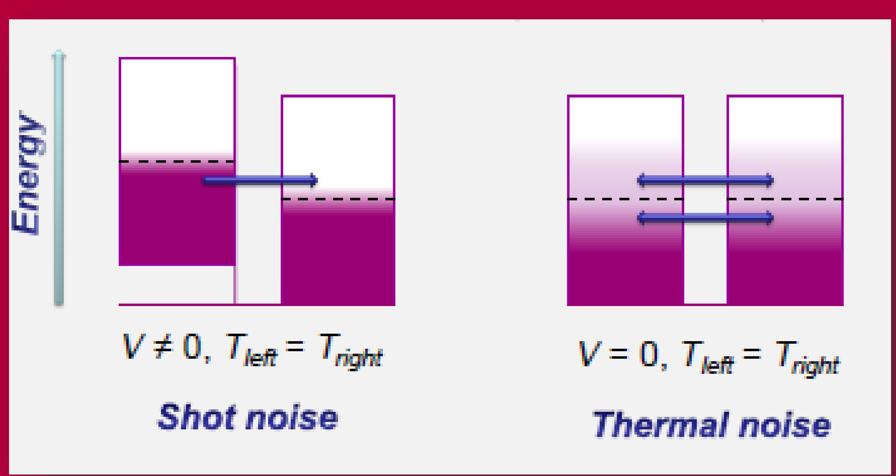
MOTIVATION

Measurements of the differential shot-noise characteristics arising from out-of-equilibrium current fluctuations in mesoscopic systems are a powerful tool to probe the nature of current-carrying excitations in quantum systems [1]. In particular, combined studies of the differential shot noise $S_I(V)$ and the Fano factor $F(V)$, defined as the ratio of average current fluctuations to the average current, can be used as an extremely effective way to characterize hybrid N/S-based systems.

The famous Blonder-Tinkham-Klapwijk (BTK) theory [2] explains the shape of the differential conductance spectra curves for N/I/S trilayers with a superconductor (S), a normal counter-electrode (N) and an insulating barrier (I) and makes it possible to calculate corresponding noise properties. In this contribution, we take a step further and develop a methodology of obtaining the differential shot noise $dS_I(V)/dV$ and the Fano factor $F(V)$ characteristics for N/I_1/S_1/I_2/S_2 heterostructures formed by five layers, remaining at the same time within the framework of the BTK approximations.



Difference between shot and thermal noises

The study [3] of current fluctuations in layered hybrid structures formed by an N counter-electrode, an insulator, and a two-band superconductor revealed the presence of two energy bands whose contributions were summed up. In the case of N/I_1/S_1/I_2/S_2 structures, the second gap "hides" behind the first, and the results obtained are of a fundamentally different nature.

REFERENCES

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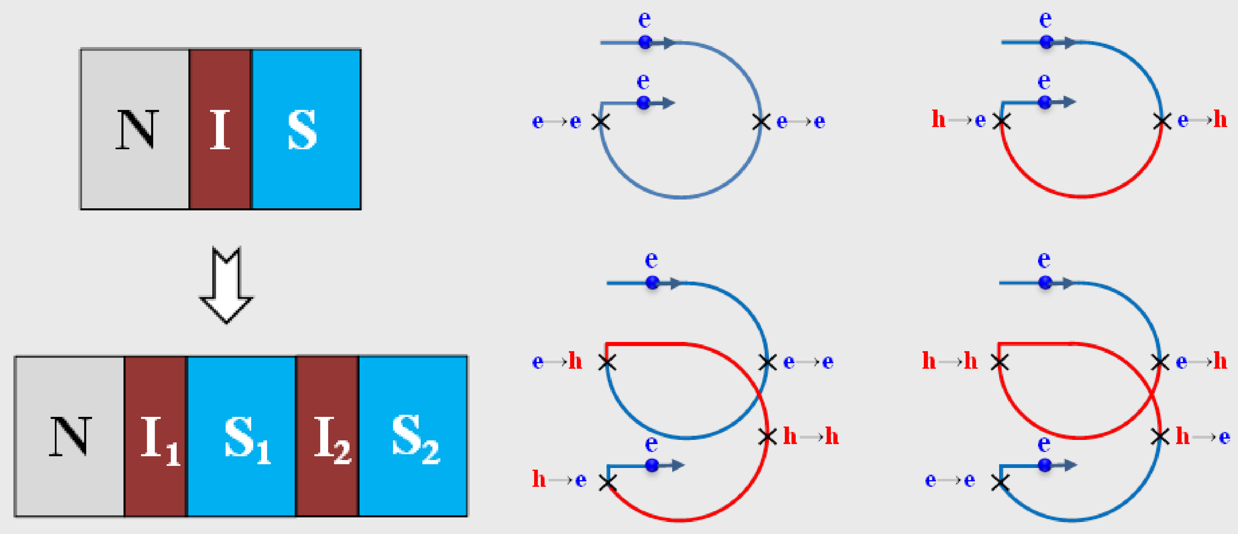
THEORETICAL MODEL

Our main idea based on the methods of scattering theory is to interpret the charge transmission across a multilayer as a chain of an infinite number of interface scattering events, sequentially increasing the number of layers and applying the formula for a double-barrier system at each step [4].



Zero-frequency limit of the current-noise spectral density.

$$S = \frac{4e^2}{h}\int d\varepsilon \left\{ f_L(\varepsilon,\mu_L,T_L)(1-f_R(\varepsilon,\mu_R,T_R)) + f_R(\varepsilon,\mu_R,T_R)\left(1-f_L(\varepsilon,\mu_L,T_L)\right)\right\} A(\varepsilon) \qquad R^{ee}(\varepsilon) = \left|r^{ee}(\varepsilon)\right|^2$$

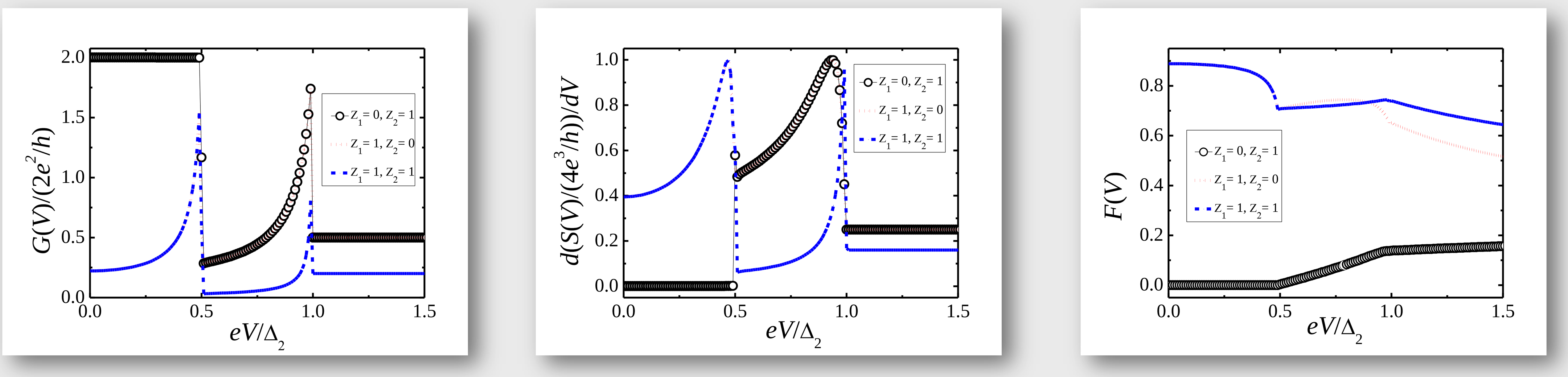
$$A(\varepsilon) = R^{ee}(\varepsilon)\left[1-R^{ee}(\varepsilon)\right] + R^{eh}(\varepsilon)\left[1-R^{eh}(\varepsilon)\right] + 2R^{ee}(\varepsilon)R^{eh}(\varepsilon) \qquad R^{eh}(\varepsilon) = \left|r^{eh}(\varepsilon)\right|^2$$

Two examples of the Andreev-reflection amplitudes for an NIS junction.

$$r^{eh\rightarrow}_{NI1nS1n}(\varepsilon) = t^{ee}_{NI1N}(1 + r^{eh}_{NS1N}(\varepsilon) r^{hh}_{NI1N} r^{he}_{NS1N}(\varepsilon) r^{ee}_{NI1N} + \ldots) r^{eh}_{NS1N}(\varepsilon) t^{hh}_{NI1N}$$

$$r^{eh\leftarrow}_{NI1nS1n}(\varepsilon) = r^{eh}_{NS1N}(\varepsilon) + t^{ee}_{NS1N}(1 + r^{eh}_{NS1N}(\varepsilon) r^{hh}_{NI1N} r^{he}_{NS1N}(\varepsilon) r^{ee}_{NI1N} + \ldots) r^{ee}_{NI1N} r^{eh}_{NS1N}(\varepsilon) r^{hh}_{NI1N} t^{hh}_{NS1N}(\varepsilon)$$

NUMERICAL SIMULATIONS



Differential conductance, differential shot noise, and Fano factor for three types of N/I_1/S_1/I_2/S_2 junctions with the ratio of energy gaps $\Delta_2/\Delta_1 = 2$. Barrier parameters are shown in the figures. Notice that each characteristic has its own specific features that distinguish it from others.

CONCLUSIONS

Our calculations show fundamental differences between the results expected for single N/I/S and two-barrier N/I_1/S_1/I_2/S_2 junctions. New features that are absent in the BTK theory include

(i) the appearance of a significant conductance dip in the voltage range between the two gaps
(ii) the ratio of the zero-bias conductance to that at voltages above the larger gap can significantly exceed the value of 2 expected from the BTK approach
(iii) the shapes of the two differential characteristics strongly differ for voltage biases below the smaller energy gap for an ideal point contact ($Z_1 = 0$)
(iv) in contrast to the Fano factor, the two differential characteristics exhibit a coherence peak at the higher energy gap even when the second barrier is absent.

These results show that the point-contact noise spectroscopy, providing direct information on the amplitude and symmetry of the superconducting order parameter and offering versatility in probing various regions of superconductors is also a source of information about the spatial variation of the order parameter.

ACKNOWLEDGEMENTS

Financované Európskou úniou NextGenerationEU | PLÁN OBNOVY | ÚRAD VLÁDY SLOVENSKEJ REPUBLIKY | VA/A

E.Zh. acknowledges the EU NextGenerationEU financial support through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00140. The work was partially supported by the German-Ukrainian collaborative project “Controllable quantum-information transfer in superconducting networks” (DFG project SE 664/21-1, No. 405579680).