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«Magnetic proximity effect in superconductor/ferromagnet heterostructures: dependence on the number of superconducting monolayers»

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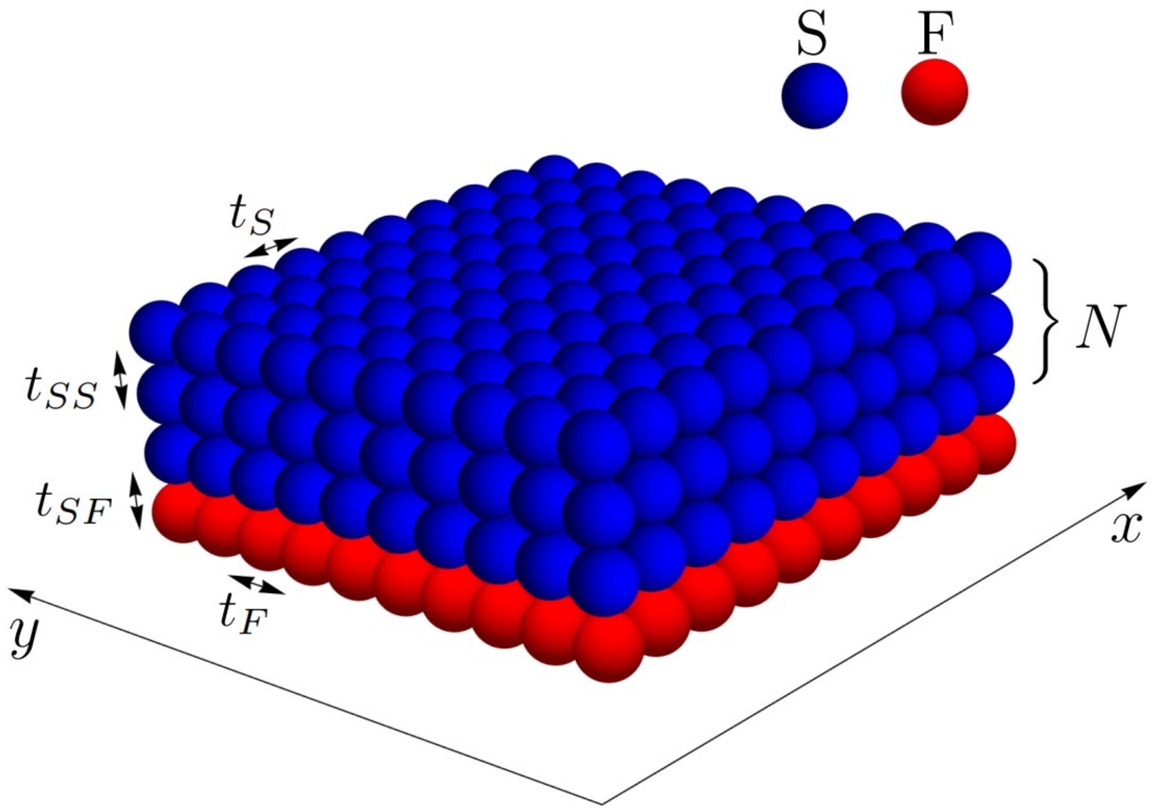
Contents

Considered structure

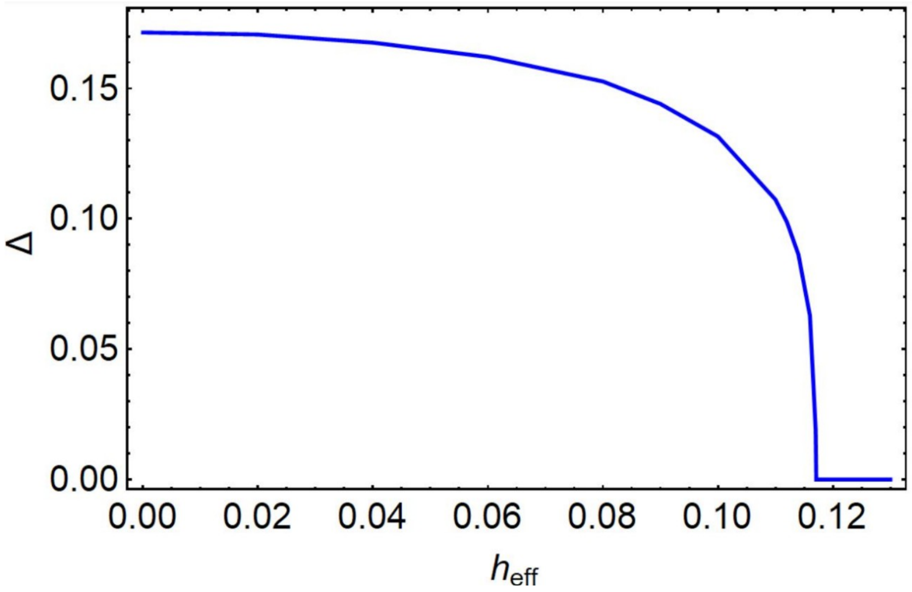
- Van-der-Waals superconductor/ferromagnet heterostructure



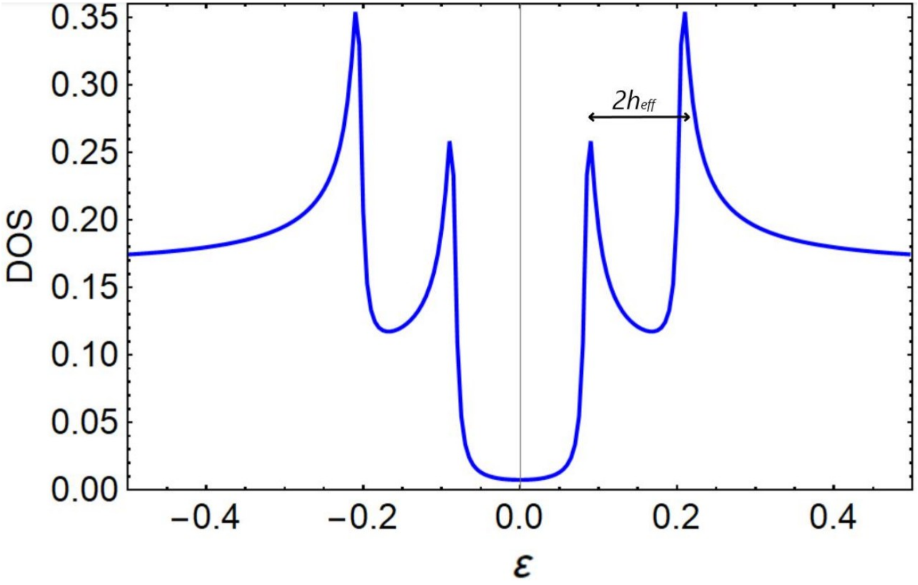
Research problem

Background (thin-film S/F heterostructure): $h_{eff} = \nu_F d_F h/(\nu_S d_S + \nu_F d_F)$ [2]

The order parameter is suppressed by an effective exchange field which is induced by the ferromagnet.



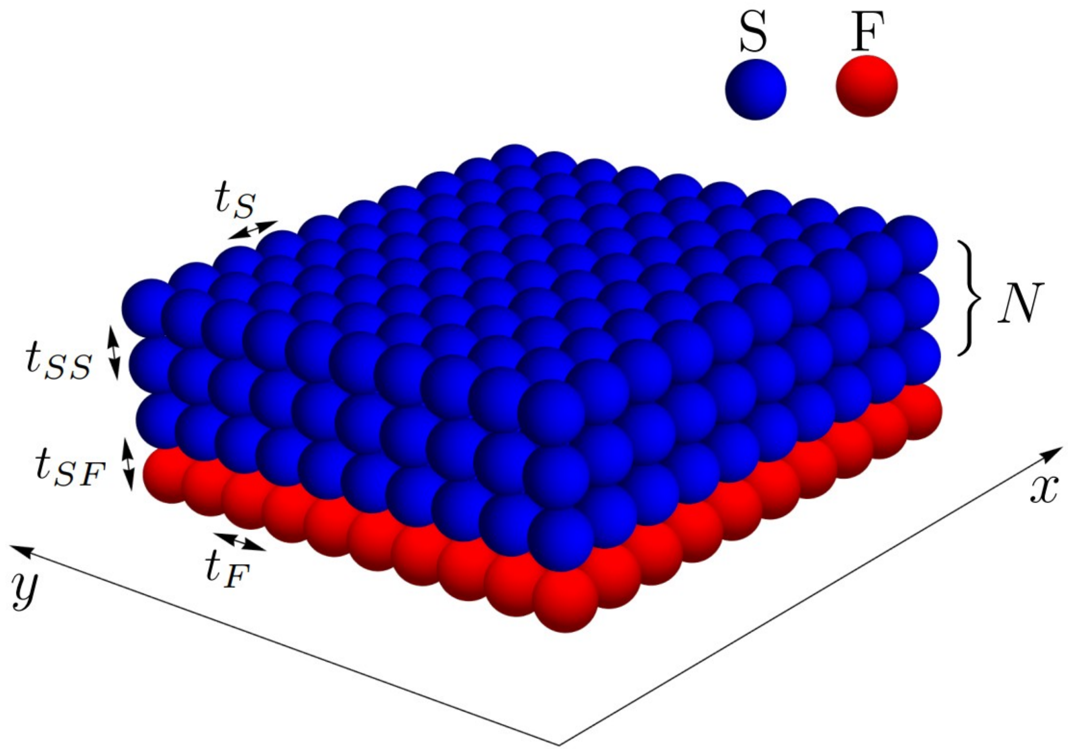
The typical behavior of the order parameter in the thin-film F/S structure.



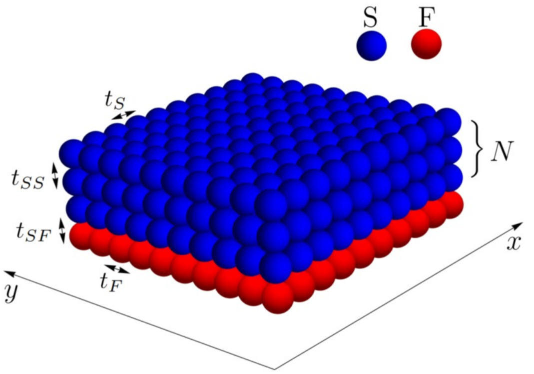
The typical shape of the electronic DOS in the thin-film F/S structure.

Research problem

- The problem of our interest is to analyse how the Δ(h) dependence changes when the number of superconducting layers in vdW heterostructure increases.



Model



- Hamiltonian of the electron system:

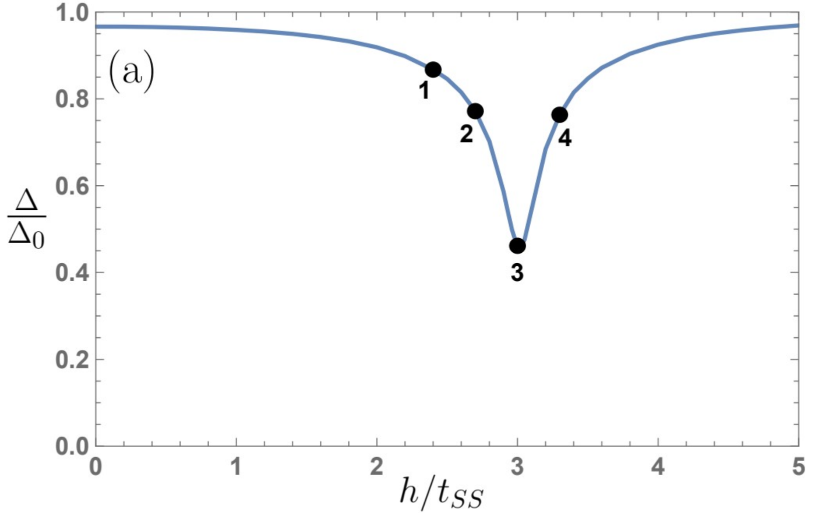
$$\hat{H} = -t_F \sum_{<\boldsymbol{ij}>,\sigma} \hat{\psi}^{0+}_{\boldsymbol{i}\sigma} \hat{\psi}^{0}_{\boldsymbol{j}\sigma} - t_S \sum_{n=1}^{N} \sum_{<\boldsymbol{ij}>,\sigma} \hat{\psi}^{(n)+}_{\boldsymbol{i}\sigma} \hat{\psi}^{(n)}_{\boldsymbol{j}\sigma} -$$

$$-t_{FS} \sum_{\boldsymbol{i}\sigma} (\hat{\psi}^{0+}_{\boldsymbol{i}\sigma} \hat{\psi}^{1}_{\boldsymbol{i}\sigma} + \hat{\psi}^{1+}_{\boldsymbol{i}\sigma} \hat{\psi}^{0}_{\boldsymbol{i}\sigma}) - t_{SS} \sum_{n=1}^{N-1} \sum_{\boldsymbol{i}\sigma} (\hat{\psi}^{(n)+}_{\boldsymbol{i}\sigma} \hat{\psi}^{(n+1)}_{\boldsymbol{i}\sigma} + \hat{\psi}^{(n+1)+}_{\boldsymbol{i}\sigma} \hat{\psi}^{(n)}_{\boldsymbol{i}\sigma})$$

$$-\mu_F \sum_{\boldsymbol{i}\sigma} \hat{\psi}^{0+}_{\boldsymbol{i}\sigma} \hat{\psi}^{0}_{\boldsymbol{i}\sigma} - \mu_S \sum_{n=1}^{N} \sum_{\boldsymbol{i}\sigma} \hat{\psi}^{(n)+}_{\boldsymbol{i}\sigma} \hat{\psi}^{(n)}_{\boldsymbol{i}\sigma} +$$

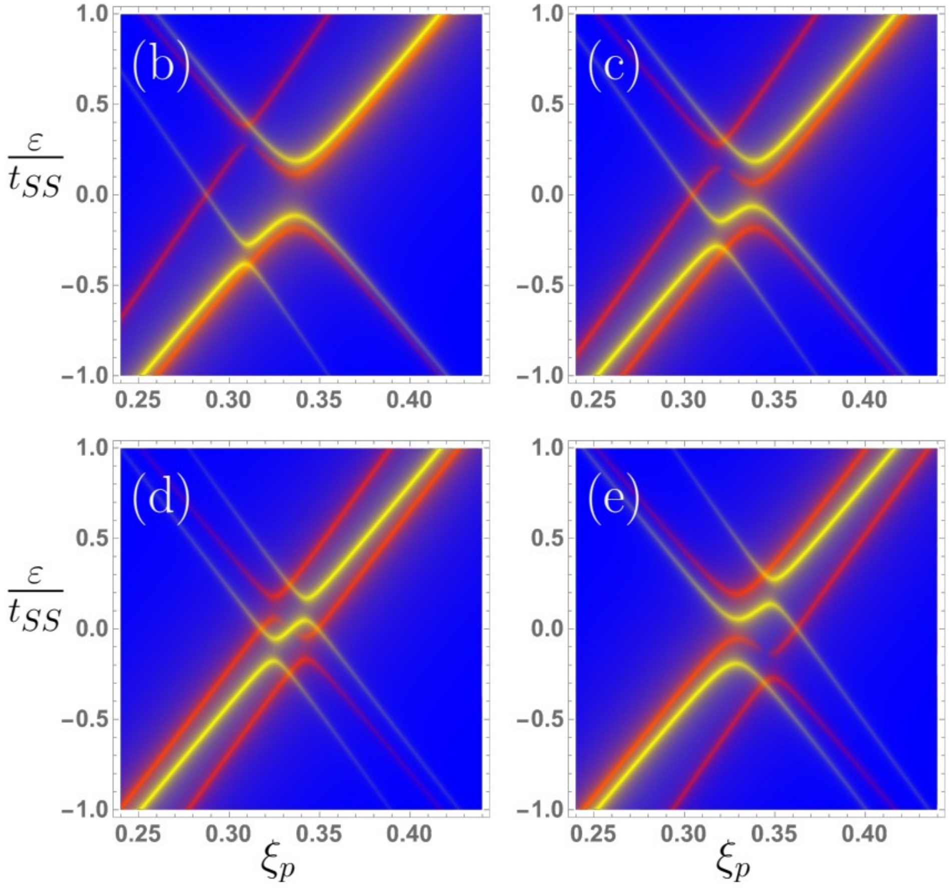
$$+ \sum_{n=1}^{N} \sum_{\boldsymbol{i}} (\Delta_{\boldsymbol{i}} \hat{\psi}^{(n)+}_{\boldsymbol{i}\uparrow} \hat{\psi}^{(n)+}_{\boldsymbol{i}\downarrow} + \Delta^{*}_{\boldsymbol{i}} \hat{\psi}^{(n)}_{\boldsymbol{i}\downarrow} \hat{\psi}^{(n)}_{\boldsymbol{i}\uparrow}) + \sum_{\boldsymbol{i}} \hat{\psi}^{0+}_{\boldsymbol{i}\alpha} (\boldsymbol{h_i \sigma})_{\alpha\beta} \hat{\psi}^{0}_{\boldsymbol{i}\beta}$$

Structure with one layer of the superconductor



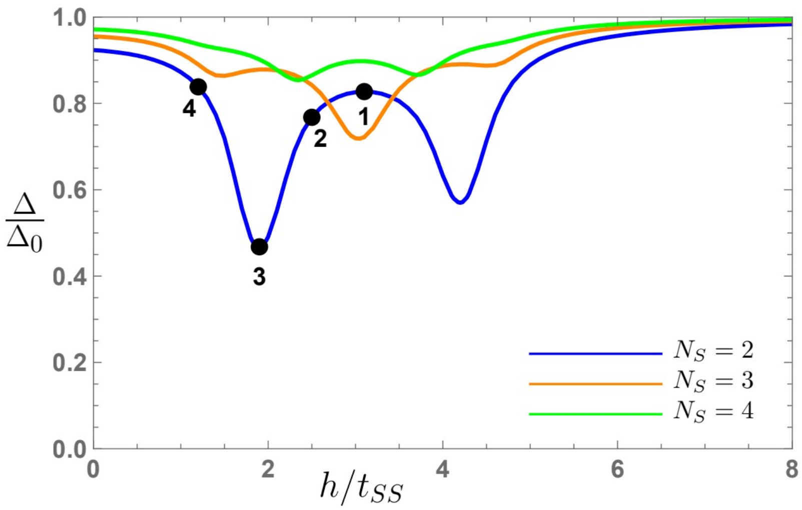
Δ(h)

N_S=1, μ_F=2, μ_S=4, t_{FS}=0.23, $t_{S(F)}$=12(15), T=0.04



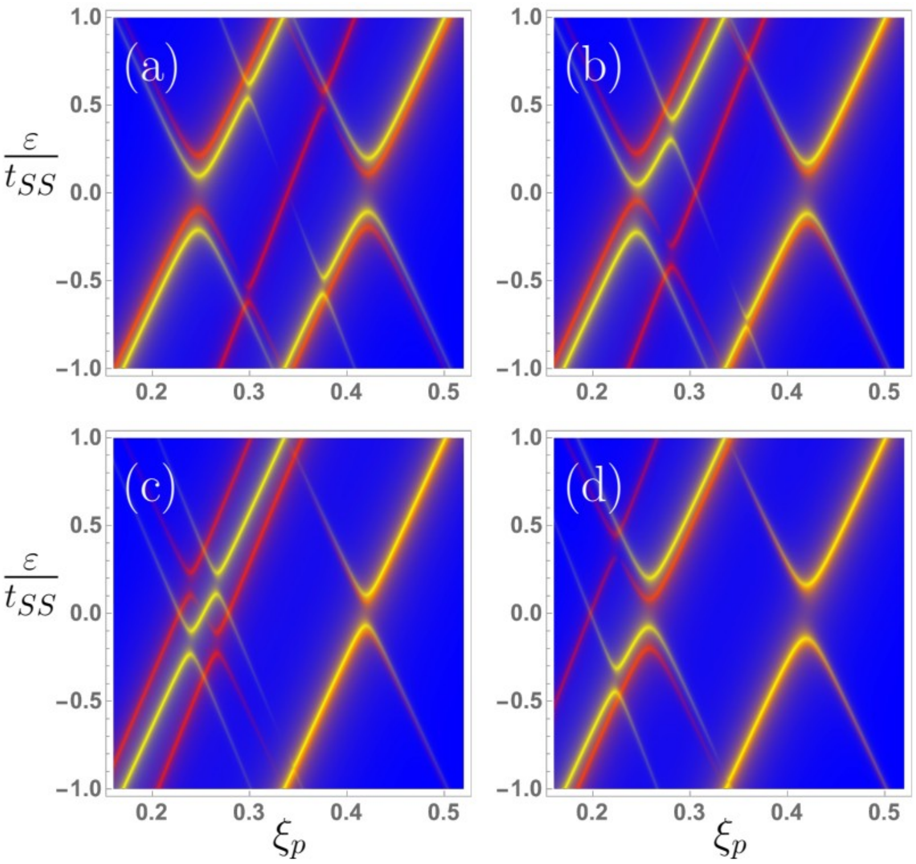
$$\xi(p) = -2(cos(p_x a) + cos(p_y a))$$

Structure with several layers of the superconductor



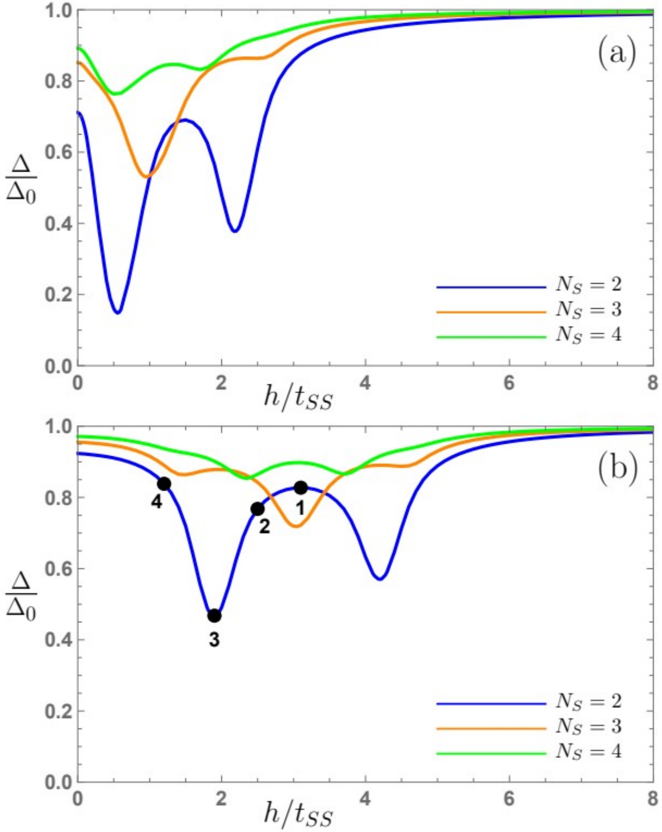
Δ(h)

μ_F=2, μ_S=4, t_{FS}=0.5, $t_{S(F)}$=12(15), T=0.04



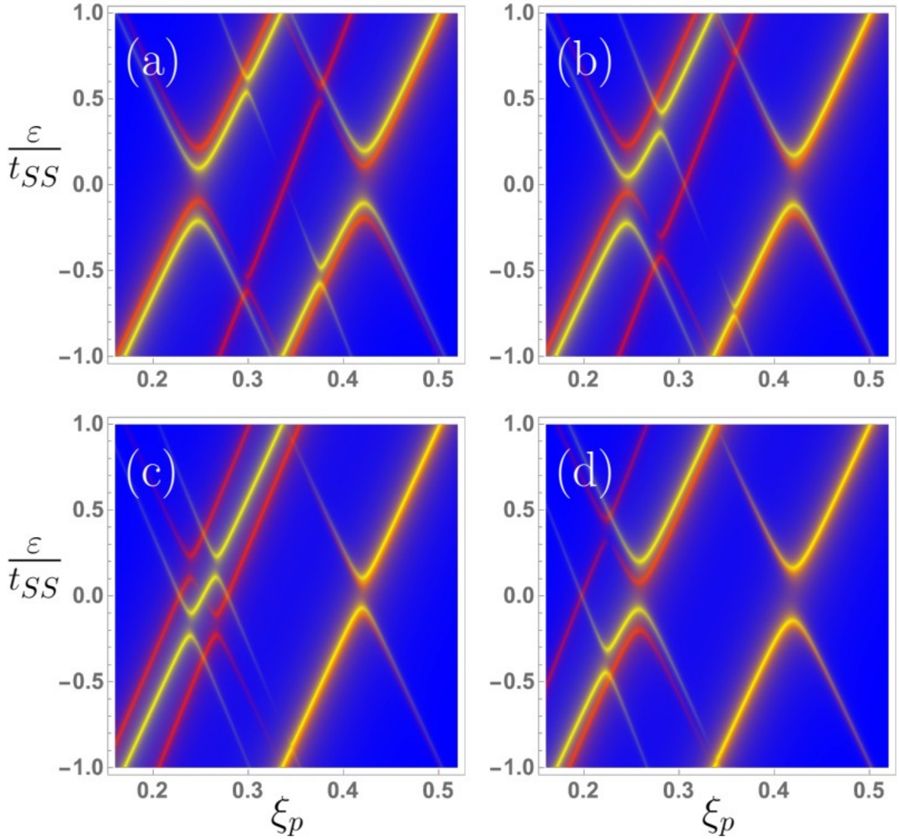
$$\xi(p) = -2(cos(p_x a) + cos(p_y a))$$

Structure with several layers of the superconductor



(a) μ_F=4, (b) μ_F=2

μ_S=4, t_{FS}=0.5, $t_{S(F)}$=12(15), T=0.04

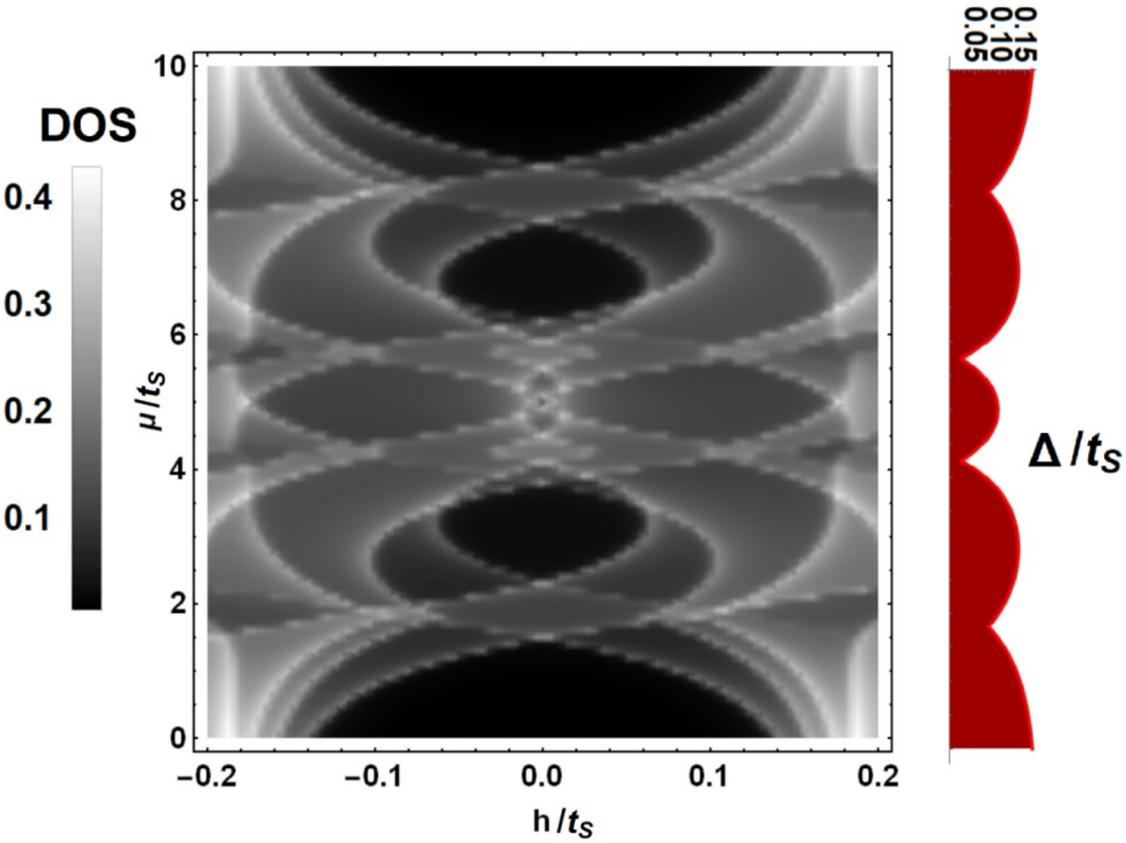


$$\xi(p) = -2(cos(p_x a) + cos(p_y a))$$

Possible applications

The degree of hybridization of the electronic spectra can be also controlled by μ_F via applying the gating potential [2].

Nonmonotonic dependence $\Delta(\mu_F)$ can be probed by measuring DOS.



N_S=2

Conclusions

1. The hybridization mechanism of the magnetic proximity effect clearly manifests itself with change of the number of layers. It is shown that heterostructures with 2-3 superconducting layers have the most pronounced nonmonotonic dependence of the superconducting order parameter on the exchange field of the F layer.

2. The nonmonotonic dependence of the order parameter can be also obtained via gating.

3. Due to the hybridization proximity effect the gap and the Zeeman splitting of the DOS can be varied by gating.

References

[1] Bergeret, F. S. and Volkov, A. F. and Efetov, K. B., Phys. Rev. Lett., 2001

[2] G. A. Bobkov et al., 2024, https://doi.org/10.48550/arXiv.2405.07575

Thank you for your attention!