One year in Leiden

September 2004 – August 2005

Group Meeting, 31/08/2005

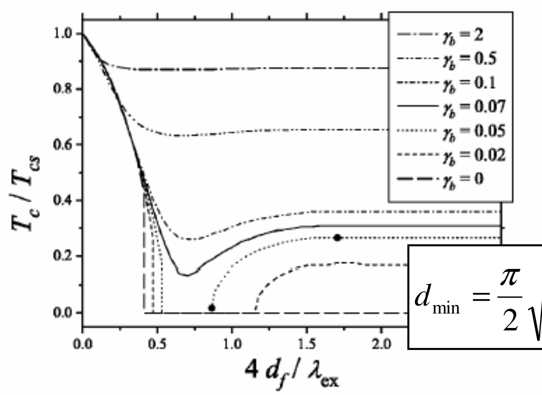
Proximity effect between a Superconductor (S=Nb) and a Weak Ferromagnet (F=$Pd_{0.81}Ni_{0.19}$)

- $T_c(d_S, d_F)$ dependence in Nb/PdNi bilayers
- $J_{dp}(d_F)$ behaviour in Nb/PdNi bilayers
- Magnetization switching in PdNi/Nb/PdNi trilayers?

$T_c(d_F, d_S)$ dependence in Nb/PdNi bilayers (I)

Motivation: In S/F structures two competing orders coexist, resulting in a rich variety of phenomena, such as the nonmonotonic behaviour of the critical temperature as a function of the thickness of the ferromagnetic layer.

The theory: based on the linearized Usadel equations, with the boundary conditions derived by Kupriyanov and Lukichev expressed in terms of two parameters



$$d_{\min} = \frac{\pi}{2}\sqrt{\frac{\hbar D_F}{E_{ex}}} = \frac{\pi}{2}\xi_F = \frac{\lambda_{ex}}{4}$$

FIG. 3. Characteristic types of $T_c(d_f)$ behavior. The thickness of the F layer is measured in units of the wavelength λ_{ex} defined in Eq. (40). The curves correspond to different values of γ_b. The exchange energy is $E_{ex}=150$ K; the other parameters are the same as in Fig. 2. One can distinguish three characteristic types of $T_c(d_f)$ behavior: (1) a nonmonotonic decay to a finite T_c with a minimum at particular d_f ($\gamma_b=2$; 0.5; 0.1; 0.07), (2) a reentrant behavior ($\gamma_b=0.05$;0.02), and (3) a monotonic decay to $T_c=0$ at finite d_f ($\gamma_b=0$). The bold points indicate the choice of parameter corresponding to Fig. 6.

$$\gamma = \frac{\rho_S \xi_S}{\rho_F \xi^*{}_F}, \qquad \gamma_b = \frac{R_B S}{\rho_F \xi^*{}_F}$$

$$\left(\xi_S = \sqrt{\frac{\hbar D_S}{2\pi k_B T_{cS}}}, \quad \xi^*{}_F = \sqrt{\frac{\hbar D_F}{2\pi k_B T_{cS}}} \right)$$

γ measures the strength of the proximity effect between S and F

γ_b describes the effect of the interface transparency

$\gamma_b = 0$ Perfectly transparent interface

$\gamma_b = \infty$ Vanishingly small boundary transparency

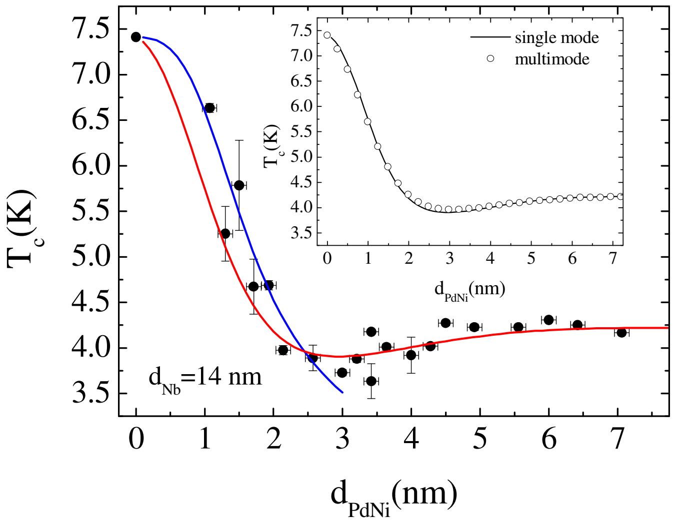
Two possible approximations:

-Multi-mode: all the Matsubara frequencies, $\omega_n = \pi T_c(2n+1)$ are taken into account

-Single-mode: only the first frequency, $\omega_0 = \pi T_c$, is considered

Fominov et al., PRB **66**, 014507 (2002)

$T_c(d_F, d_S)$ dependence in Nb/PdNi bilayers (II)

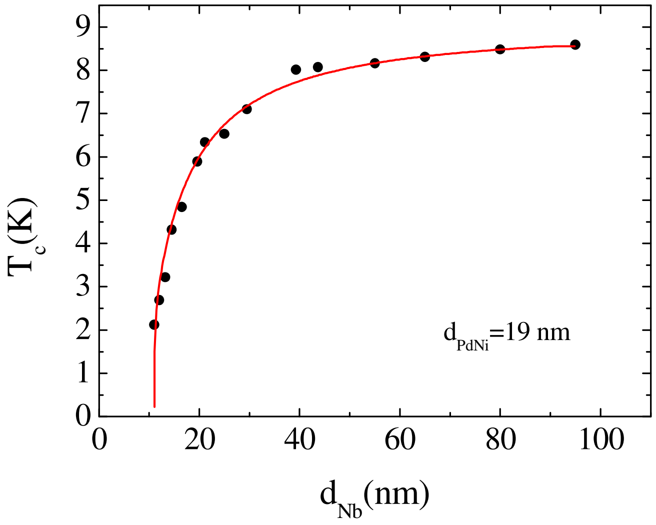


The behaviour of the experimental $T_c(d_{PdNi})$ data is reproduced by the theory using the values of the microscopical parameters:

ρ_S=17 μΩcm, ξ_S=5.8 nm, T_{cS}=7.41 K

ρ_F=64 μΩcm, l_F=3.5 nm, ξ^*_F=6.2 nm

- Not big difference between single and multi-mode
- Small d_F regime: microscopical parameters of the F layer strongly depend on the thickness



The behaviour of the experimental $T_c(d_{Nb})$ data is reproduced by the theory using the values of the microscopical parameters:

ρ_F=21 μΩcm, ξ^*_F=6.2 nm

ξ_S=5.8 nm

Also in this case the thickness dependence of the microscopical parameters of the S layer must be taken into account

The theory reproduces the experimental $T_c(d_{PdNi})$ and $T_c(d_{Nb})$ data with the same fitting parameters

E_{ex}=230 K=19.8 meV ⇒ ξ_F=2.6 nm

$\gamma_b \approx 0.13$

$J_{dp}(d_F)$ behaviour in bilayers (I)

Definition: Supposing to prevent vortex motion in a superconducting sample, than the depairing current is the ultimate critical current that a superconductor can support. It is reached when further acceleration of the Cooper pairs leads to such a decrease of their number than the superconducting state collapses.

Motivation: a more sensitive tool to study the order parameter changes

Fe/Pb/Fe trilayers

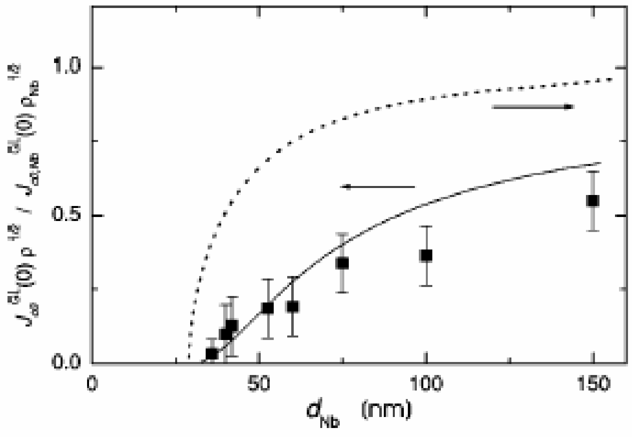


FIG. 5. $J_{c0}^{GL}(0)\rho^{1/2}$ of the Fe/Nb/Fe trilayers scaled on the value of the single Nb layer vs superconducting layer thickness $d_{\rm Nb}$. The result of the model calculations for $\gamma = 34.6$, $\gamma_b = 42$ is also plotted (solid line) as well as the dependence of the critical temperature T_c/T_{c0} on $d_{\rm Nb}$ (dashed line) for the same parameters.

Geers et al., PRB **64**, 094506 (2001)

Nb/$Pd_{0.89}Ni_{0.11}$ bilayers

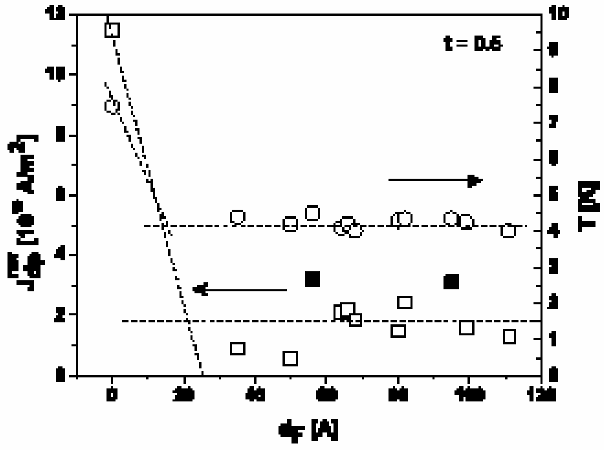
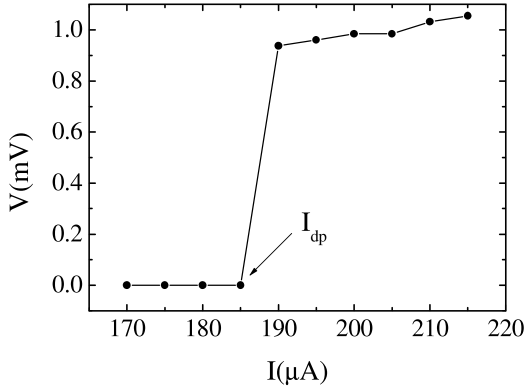


Figure 4.13: Depairing current density J_{dp}^{nor} (open squares) at $t = 0.5$ and critical temperature T_c (open circles) of Nb/PdNi bilayers as a function of ferromagnet thickness d_F. Black solid squares indicate the samples with the deviating values of J_{dp}. Dashed lines are guides to the eye.

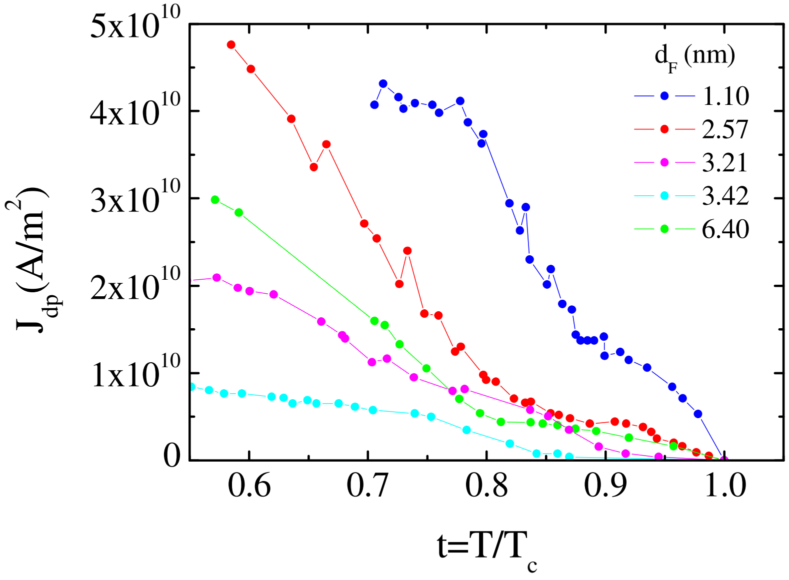
Rusanov, PhD thesis

$J_{dp}(d_F)$ behaviour in bilayers (II)

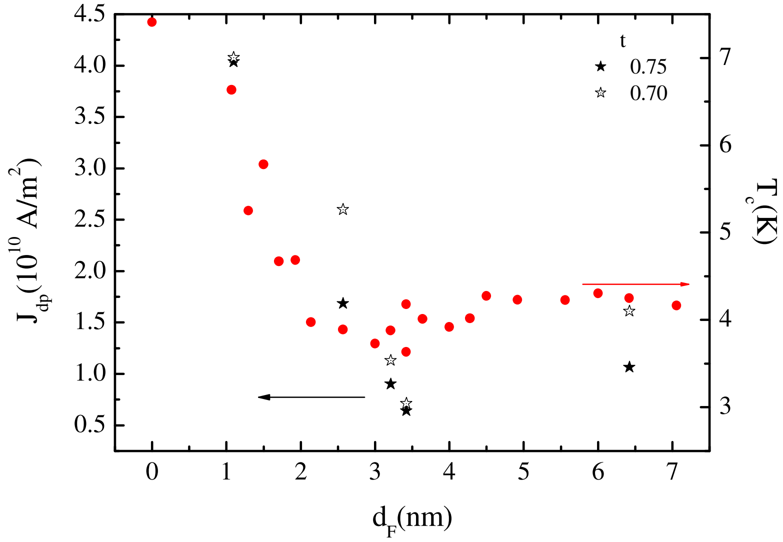
- 1.5 µm wide strip (e-beam lithography + Ar-ion etching)
- Pulsed current technique (3-5 ms pulses)



Clear jump from the superconducting to the normal state

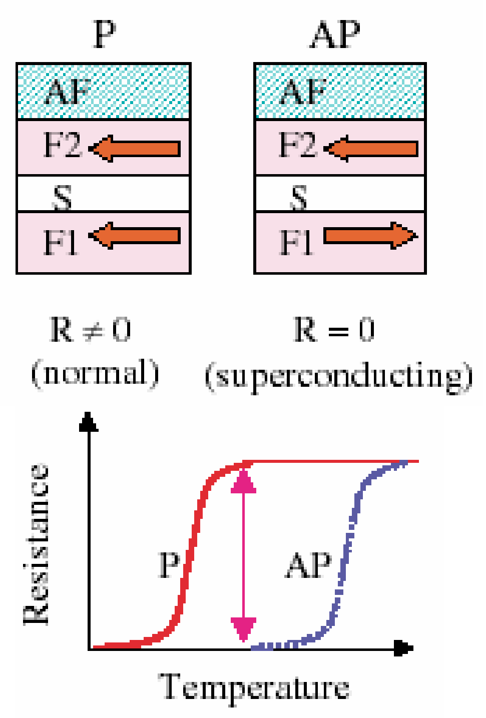


Temperature dependence of J_{dp}



Thickness dependence of J_{dp}

Magnetization switching in PdNi/Nb/PdNi trilayers? (I)



Motivation:

- The superconducting state in a F/S/F trilayer depends on the relative magnetic orientations of the F layers: the critical temperature is reduced when the ferromagnets are magnetized in the same direction.

- The superconducting spin switch is a system in which is possible to control the occurence of superconductivity by changing the relative orientations of the F layers.

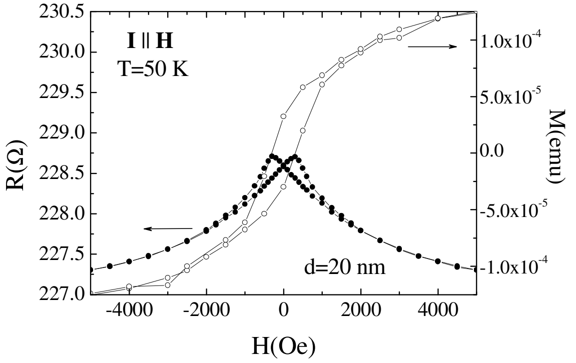
Requirements:

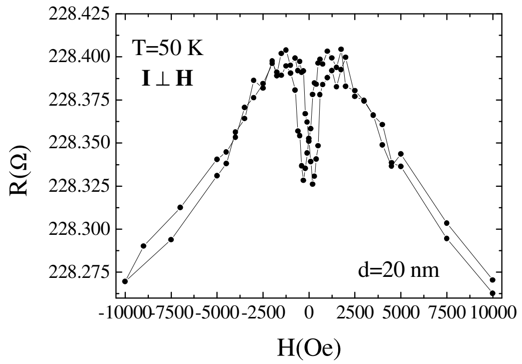
- Good interface transparency of the S/F barriers
- Properly chosen value of d_S ($d_S \approx \xi_S$)
- Sharp switching of the F layers

Tagirov, PRL **83**, 2058 (1999); Gu et al., PRL **89**, 267001 (2002)

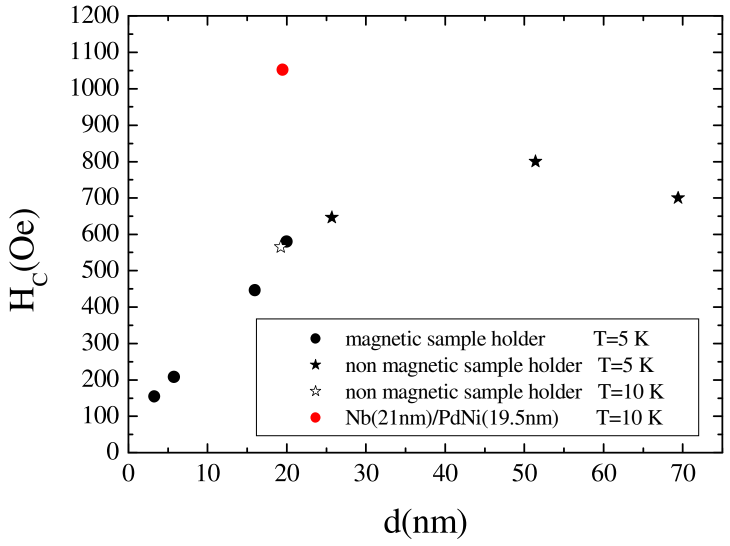
Magnetic properties

PdNi single films





reversed behaviour in the AMR shape



Use H_c thickness dependence to realize the switching? But…

PdNi/Nb/PdNi trilayers