Spin relaxation length for medium-energy electrons in palladium thin films

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Abstract. The development of spintronics (the field of science that examines the behavior of systems, based not only on charge transfer, but on magnetic properties of nano-objects as well) requires study of various magnetic and electrical properties of nanoscale systems. To create a new device it is often important to know a length of spin relaxation not only for electrons with energies close to the Fermi surface, but also with energy of several hundred eV. In this study we measured such lengths in palladium at room temperature. Results obtained by secondary electron spectroscopy show that spin relaxation length for energy 100 eV is 11.9±1.6Å and for energy 500 eV is 27.1±10.5Å.

1. Introduction
When electron current goes through a solid, relaxation processes are observed that lead to changes in current properties. Electron energy loss is the simplest effect which is associated with inelastic collisions of electrons with their environment. Number of electrons which passed a certain distance without inelastic scattering is characterized by inelastic mean free path and is well studied and for most of substances can be represented by a universal curve [1].

However, the spin relaxation length, in other words length at which the polarization of the beam decreases e times, is still studied poorly. One way to determine this length is to measure conductivity dependence on magnetization for the ferromagnetic material layers. This method allows determination of mean free path with respect to the spin relaxation for electrons with energies close to Fermi level [2]. Nevertheless, for developing new devices it is often important to determine this parameter for electrons with energies of several hundreds eV. For this task suitable method is secondary electron spectroscopy. Study of transport losses for polarized electrons with different energy can be used for determination of spin relaxation length in material, and it is the method we used in this study.

Palladium was chosen as a material for experiments. It is light enough to have significant spin-orbit interaction and possesses a simple electronic structure with filled electron shells. It is vacuum material, can be easily deposited and etched afterwards.

2. Experimental setup
The experimental setup was based on an ultra-high vacuum chamber equipped with facilities for thin-film deposition, argon bombardment and electronic spectrometry [3] including Mott detector for spin polarized measurements [4, 5]. Schematic representation of the setup is shown on figure 1. The deposition source was constructed out of ceramic crucible that was put inside tungsten wire coil. Later was used to heat ceramic and evaporate palladium from inside of it. Main part of argon etching system
was ion gun with thermionic cathode and electron gas ionization. Spectrometry setup consisted of
dispersive energy analyzer (two pass cylindrical mirror, specially designed for collimation into
polarimeter) and classical Mott polarimeter for electron spin polarization measurements.

Basic pressure in the system was $8 \times 10^{-10}$ Torr. The temperature remained equal to room temperature
except for sample and chamber annealing processes.

The main purpose of the experiment was to measure length of spin relaxation in palladium thin films.
The basic idea that we used was to record electron polarization hysteresis loops and thus make
conclusions about polarization loss rate. This required us to perform the following steps: preparation of
single crystal’s surface (annealing and ion bombardment), calibration of evaporation source, deposition
of thin films (Section 3), recording the hysteresis loops for various film thicknesses and different
energies of secondary electrons (Section 4).

In the experiment the frame-shaped FeNi$_3$ (110) single crystal was used. Before the experiment, the
crystal was annealed in ultrahigh vacuum. Selected single crystal was used as a robust source of
polarized electrons for ongoing spectroscopic measurements. For cleaning off contaminants argon
bombardment was applied. Argon ions had an energy of 500 eV, the pressure in the system during the
etching procedure was $5 \times 10^{-5}$ Torr of argon. Control of surface’s purity was made by means of Auger
electron spectroscopy. The cleaning process continued until peaks of typical surface contaminants
(carbon, oxygen) disappeared. An example of spectrum after bombardment is shown on Figure 2. Clean
Auger spectrum allowed us to state that the crystal’s surface was atomically clean.

The magnetization of the sample was carried out as follows. Around one of the sides of the frame
coil was wound. Current passing through the coil produces a magnetic field in a closed frame. After
magnetization ferromagnetic crystal becomes a source for spin polarized secondary electrons.

![Figure 1. Sketch of experimental setup](image1)

![Figure 2. Auger spectrum of clean FeNi$_3$ sample](image2)
3. Film growth

For deposition of palladium onto the FeNi$_3$ surface thermal evaporation method was used. For success of this work it was essential to have precise data on film deposition rates. More than that, growth of films is the key factor, as for our spin relaxation calculations to be correct it is necessary to have all outgoing electrons to pass equal distances in the studied medium.

![Auger spectra of Pd thin film](image1)

Figure 3. Auger spectra of Pd thin film

Example of thick palladium film spectrum is shown in figure 3. In thermal evaporation deposition rate depends on the current flowing through the heating coil. To calibrate the speed of Pd deposition we needed to choose a heater current, and then deposit Pd from the source onto the crystal surface with equal time intervals to measure amplitude of peaks of Auger transitions in the film and in the substrate. Such measurements in the case of layered growth must lie on an exponential curve. In this case, $I \sim \exp(-d/l)$, where $I$ is the signal amplitude, $d$ is the film thickness, $l$ mean free path for electrons in the film is Pd. Knowing the mean free path in the Pd [1], it is possible to link the deposition rate and the thickness of the film on the surface of substrate. The dependence of intensity for substrate peak (Ni 61 eV) and film-material peak (Pd 330 eV) for different thicknesses of film are shown on figure 4. The deposition time is converted into a thickness for convenience of further comparison.

![Calibration of Pd evaporation source by Auger peaks amplitude](image2)

Figure 4. Calibration of Pd evaporation source by Auger peaks amplitude
4. Magnetic measurements

The base of magnetic measurements lay on the measurement of amplitude for electron polarization hysteresis loops for different film thicknesses and different energies of secondary electrons. In our experiment we choose 100 and 500 eV as energies for analysis of secondary electrons, but in following work we will make energy range more complete. Under the hysteresis loop in the case of secondary electrons one should understand result of the following measurement: at fixed analyser’s energy we scan through different values of magnetic field inside the frame and measure electron polarization. Result of such measurement gives, really, a hysteresis loop, because electron polarization is tightly connected with sample magnetization and measurements of polarizations were made for different coil currents and thus different applied magnetic field.

Examples of the hysteresis loops for clean crystal and various films deposited onto the crystal surface for 100 eV electrons are shown in figure 5.

By amplitude of the hysteresis loop we can determine polarization of the electrons that passed through Pd thin film and exited into vacuum towards the detection. From experimental results we derived a dependencies of spin relaxation length in palladium for two energies and various thicknesses. In undergoing work we plan to make those dependencies into the polarization map for better characterization of studied material. Measured electron polarization decreases exponentially (figure 5).

This allows us to assume that the polarization is lost during the electron-electron interaction and scattering on the defects [6]. The value in the denominator of exponent can be called the length of spin relaxation of electrons for a given energy in the film of Pd. When we compare the values of the inelastic mean free path with spin relaxation length (figure 4 and figure 5), we see that the spin relaxation length...
is approximately two times greater than the mean free path. That characterizes Pd as a promising material for the polarization transfer in a spintronic devices at room temperature.

The results of this work can be used to create a detector of spin polarization [7]. The main idea of that is to create optical detector of free-electron spin. For this task authors needed a substance that will cover the surface of the detector. In addition to the protective function coating is used as a moderator before electron spin optical analyser. For the application it is very important that the length of spin relaxation for used material to exceed the mean free path at least few times. So, palladium can be used as such a material reducing losses of polarization in the coating.

Another interesting application for palladium film can be the creation of highly polarized positrons sources [8]. Often radioactive isotopes of sodium are used as a positron source. Resulting positron beam is polarized, but has very high energy (few MeV). For applications in spectroscopy, the beam should be slowed, and for that W crystal is often used. After passing through the tungsten crystal positrons lose most of the energy, but also lose their polarization. Replacing W with Pd can increase the polarization of the positron beam. Because, despite of the different charge, positrons and electrons, have similar mechanisms for spin loses.

5. Summary
In this study we obtained spin relaxation length in Pd thin films at room temperature. Measured relaxation length for energy 100 eV is 11,9±1,6Å and for energy 500 eV is 27,1±10,5Å.

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