Electrical and magnetic properties of ferritin: electron transport phenomena and electron paramagnetic resonance

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SUMMARY

Ferritin is a spherical protein of about 12 nm in external diameter. It is the main regulator of available iron within our bodies. The shell of ferritin promotes iron uptake. The iron is then encapsulated in a mineral form, which is called the ferritin core, protecting the iron from possible interactions with the environment. Neurodegenerative diseases, such as Alzheimer's and Parkinson's are associated with abnormal levels of iron in the body. This has generated specific interest in the study of ferritin, in particular, of its physical properties, as it might be that ferritin is malfunctioning.

This dissertation aims to explore the electrical and magnetic properties of ferritin. The electrical characterization is focused on the investigation of the current vs. voltage characteristics of single-ferritin particles, which provides valuable insights into the electron transport mechanisms within them (chapters 2, 3, 4). On the other hand, the magnetic characterization of ferritin involves the analysis and modeling of the electron paramagnetic resonance (EPR) spectra obtained from multiple ferritins, enabling a deeper understanding of the electron-spin structure within the ferritin core (chapters 5, 6).

Chapter 2 describes the fabrication of devices that permit the generation of single-electron transistors based on the trapping of single nanoparticles. The devices are based on wide self-aligned nanogap devices that include a local gate placed underneath the gap area. Gold nanoparticles of 10 and 40 nm sizes in diameter are used to test them, obtaining a mean gate coupling of 0.07 which permits the visualization of Coulomb diamond-like features within ±2 V. This fabrication method can be used to generate single-electron transistors based on different nanoparticles, such as metal/oxide-based particles, and bioparticles.

Chapter 3 focuses on the electrical characterization of single-ferritin particles trapped in self-aligned nanodevices with gaps of ~13 nm. A striking feature of single ferritin particles is that the data is in excellent agreement with the Coulomb blockade model, revealing single-electron tunneling as the main transport mechanism through them.

Chapter 4 uses the devices described in Chapter 2 to conduct three-terminal measurements on single ferritin. This leads to the successful fabrication of the first ferritin single-electron transistor.

Chapter 5 presents a 9 GHz continuous wave EPR analysis that was used to elucidate the magnetic properties of the core of human-liver ferritin. It proposes a model for the electron-spin structure of the ferritin core based on the combined analysis of EPR with magnetometry, in collaboration with magnetometry experts.

Finally, **chapter 6** investigates the potential damage in ferritin that could result from lyophilization. This study is performed from a magnetic perspective through an EPR analysis. Second, this chapter extends the model proposed in chapter 5 to include lyophilized ferritin samples from human liver and post-mortem brain tissues. The model was found to be consistent with the isolated ferritin signal of brain samples.