Heinz Nixdorf-Lehrstuhl für Biomedizinische Elektronik
Fakultät für Elektrotechnik und Informationstechnik
Technische Universität München

Superparamagnetic Nanoparticles in Picoliter Droplets for Measurements with Spin Valves

Scientific thesis for the attainment of the academic degree
Master of Science (M.Sc.)
of the Department of Electrical and Computer Engineering
at the Technical University of Munich.

Supervised by Dr.-Ing. Mathias Reisbeck
Prof. Dr. rer. nat. Oliver Hayden

Submitted by Johann Alexander Brenner
Weisbergerstraße 5a
85053 Ingolstadt
03662733

Submitted on December 4th, 2020 at Munich

Contents

1. Introduction and Motivation

2. Theoretical Prequisites

2.1. Microfluidics

2.1.1. Flow Fields

2.2. Surface Chemistry

2.2.1. Carbodiimide Crosslinker Chemistry

EDC-NHS-Activation sulfo-NHS vs. NHS

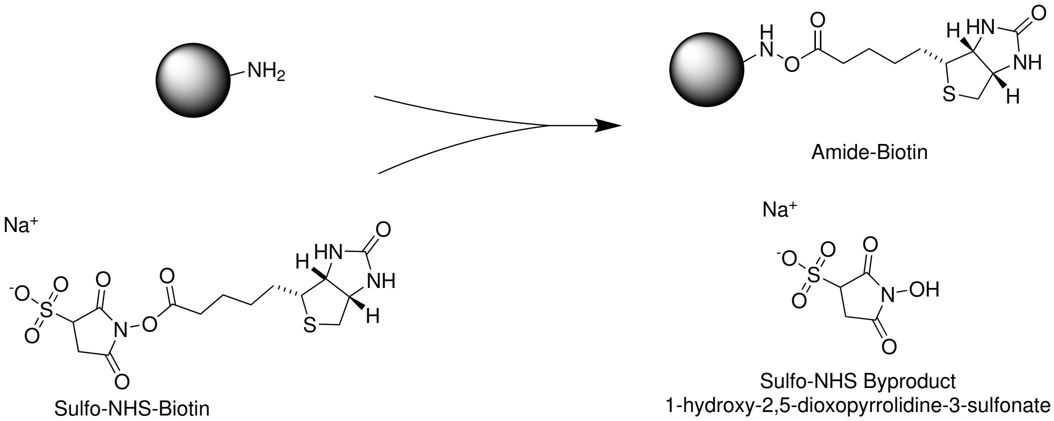

Figure 1 TestSvg

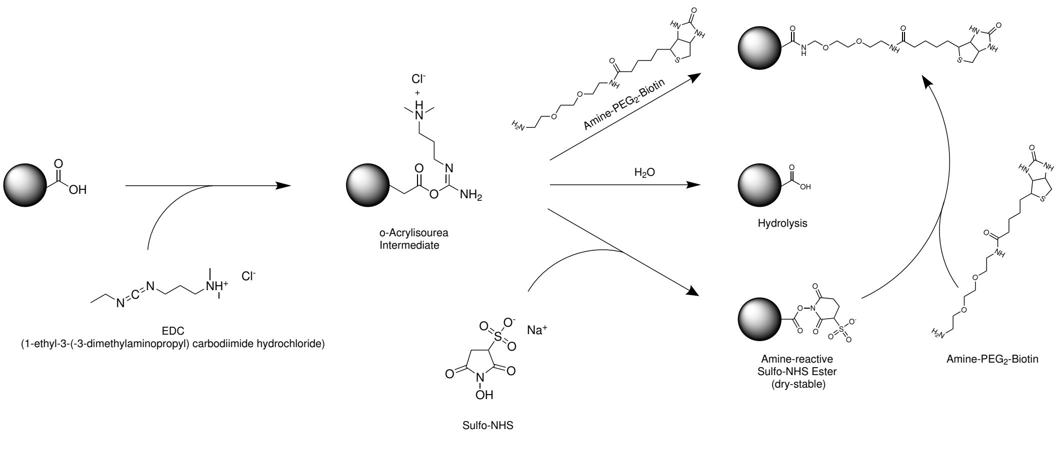

Figure 2 TestSvg

2.3. MRCyte

Short intro over MRCyte Foto of setup with arrows to necessary parts Microscope Stages PEEK holder Helmholtz coils Kepco MFLI DAQ

2.3.1. Focusing Structures

test,test

2.3.2. GMR

Different produced GMR stacks Wheatstone Bridge setup Magnet alignment

Hysteresis Alignment

test,test

2.3.3. Electrical Circuit

Ground PCB Stacked PCBs with spacer

2.3.4. Electronic Readout

test,test

Single GMR

test,test

Dual GMR

one MFLI supplies both at same freuqency. Aux Trigger tested, but no advantage.

3. Materials and Methods

test,test

4. Results

test,test

5. Discussion

test,test

6. Outlook

List of Figures

List of Tables

Bibliography

[1] A. P. Guimarães, *Principles of Nanomagnetism*. Springer International Publishing, 2017. DOI: 10.1007/978-3-319-59409-5.

[2] G. Holdridge. (Jul. 2018). "Nanotechnology timeline," National Nanotechnology Initiative.

[3] S. Munwar *et al.*, "A review on preparation of nanoparticles," *Int J Recent Sci Res*, vol. 8(8), pp. 19 057–19 060, Aug. 2017.

[4] Q. A. Pankhurst, J. Connolly, S. K. Jones, and J. Dobson, "Applications of magnetic nanoparticles in biomedicine," *Journal of Physics D: Applied Physics*, vol. 36, no. 13, R167, 2003.

[5] H. Liu and Y. Zhang, "Droplet formation in a T-shaped microfluidic junction," *Journal of Applied Physics*, vol. 106, no. 3, p. 034 906, Aug. 2009. DOI: 10.1063/1.3187831.

[6] H. Liu and Y. Zhang, "Droplet formation in microfluidic cross-junctions," *Physics of Fluids*, vol. 23, no. 8, p. 082 101, Aug. 2011. DOI: 10.1063/1.3615643.

[7] W. Schelter and H. van den Berg, "Magnetfeldsensor mit einer Brückenschaltung von magnetoresistiven Brückenelementen," Patent DE 19520206A1, Mar. 1997.

[8] H. van den Berg, "Magnetowiderstands-sensor," Patent DE 4232244A1, Mar. 1994.

[9] M.-C. Amann, *Werkstoffe der Elektrotechnik*. Lehrstuhl für Halbleitertechnologie, Aug. 2015.

[10] E. Weisstein. (Jun. 2018). "Sphere point picking," MathWorld–A Wolfram Web Resource, [Online]. Available: http://mathworld.wolfram.com/SpherePointPicking.html.

[11] E. Weisstein. (Jun. 2018). "Disk point picking," MathWorld–A Wolfram Web Resource, [Online]. Available: http://mathworld.wolfram.com/DiskPointPicking.html.

[12] Elveflow. (Jul. 2018). "Elveflow - plug and play microfluidics," ELVESYS, [Online]. Available: https://www.elveflow.com/.

[13] micromod Partikeltechnologie GmbH, *Technical data sheet - nanomag®-d-spio 50nm*, 2018.

[14] G. Li, S. Wang, and S. Sun, "Model and experiment of detecting multiple magnetic nanoparticles as biomolecular labels by spin valve sensors," *IEEE Transactions*

on Magnetics, vol. 40, no. 4, pp. 3000–3002, Jul. 2004. DOI: 10.1109/tmag.2004.830626.

[15] H. Gu, M. H. G. Duits, and F. Mugele, “Droplets formation and merging in two-phase flow microfluidics,” in *International journal of molecular sciences*, 2011.

[16] M. Helou, “Magnetic flow cytometry,” Ph.D. Thesis, Christian-Albrechts-Universität zu Kiel, 2014.

[17] I.-L. Ngo, T.-D. Dang, C. Byon, and S. W. Joo, “A numerical study on the dynamics of droplet formation in a microfluidic double t-junction,” *Biomicrofluidics*, vol. 9, no. 2, p. 024 107, Mar. 2015. DOI: 10.1063/1.4916228.

[18] F. Peters and D. Arabali, “Interfacial tension between oil and water measured with a modified contour method,” *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 426, pp. 1–5, Jun. 2013. DOI: 10.1016/j.colsurfa.2013.03.010.

[19] J. H. Xu, S. W. Li, J. Tan, and G. S. Luo, “Correlations of droplet formation in t-junction microfluidic devices: From squeezing to dripping,” *Microfluidics and Nanofluidics*, vol. 5, no. 6, pp. 711–717, May 2008. DOI: 10.1007/s10404-008-0306-4.

[20] R. Gross and A. Marx, *Spinelektronik*. 2004.

[21] Y. Xie and Q. Ji, “A new efficient ellipse detection method,” *IEEE*, 2002.

[22] M. J. Owen and P. J. Smith, “Plasma treatment of polydimethylsiloxane,” *Journal of Adhesion Science and Technology*, vol. 8, no. 10, pp. 1063–1075, 1994. DOI: 10.1163/156856194X00942.

[23] M. A. Eddings, M. A. Johnson, and B. K. Gale, “Determining the optimal pdms–pdms bonding technique for microfluidic devices,” *Journal of Micromechanics and Microengineering*, vol. 18, no. 6, p. 067 001, 2008.

[24] T. Thorsen, R. W. Roberts, F. H. Arnold, and S. R. Quake, “Dynamic pattern formation in a vesicle-generating microfluidic device,” *Physical Review Letters*, vol. 86, no. 18, pp. 4163–4166, 2001. DOI: 10.1103/physrevlett.86.4163.

[25] C. A. Basca, M. Talos, and R. Brad, “Randomized hough transform for ellipse detection with result clustering,” in *EUROCON 2005 - The International Conference on "Computer as a Tool"*, vol. 2, Nov. 2005, pp. 1397–1400. DOI: 10.1109/EURCON.2005.1630222.

[26] (2018). “Converttdms.m,” [Online]. Available: https://github.com/humphreysb/ConvertTDMS/blob/master/convertTDMS.m.

[27] C.-G. Stefanita, *Magnetism*. Springer Berlin Heidelberg, 2012. DOI: 10.1007/978-3-642-22977-0.

[28] K. H. J. Buschow and F. R. de Boer, *Physics of Magnetism and Magnetic Materials*. Springer US, 2003. DOI: 10.1007/b100503.

[29] G. C. Papaefthymiou, "Nanoparticle magnetism," *Nano Today*, vol. 4, no. 5, pp. 438–447, Oct. 2009. DOI: 10.1016/j.nantod.2009.08.006.

[30] A. Paetzold, "Thermische Stabilität und Modifizierung der magnetischen Austauschanisotropie in Schichtsystemen," Ph.D. thesis, Universität Kassel, Jul. 2002, p. 163.

[31] J. Nogués and I. K. Schuller, "Exchange bias," *Journal of Magnetism and Magnetic Materials*, vol. 192, no. 2, pp. 203–232, Feb. 1999. DOI: 10.1016/s0304-8853(98)00266-2.

[32] I. Campbell and A. Fert, "Chapter 9 transport properties of ferromagnets," in *Handbook of Ferromagnetic Materials*, Elsevier, 1982, pp. 747–804. DOI: 10.1016/s1574-9304(05)80095-1.

[33] P. Gravesen, J. Branebjerg, and O. S. Jensen, "Microfluidics-a review," *Journal of Micromechanics and Microengineering*, vol. 3, no. 4, pp. 168–182, Dec. 1993. DOI: 10.1088/0960-1317/3/4/002.

[34] B. Wolfrum, "Hydraulic Circuit Analysis," *BioMEMS and Microfluidics*, 2018.

[35] J. H. Xu, S. W. Li, J. Tan, Y. J. Wang, and G. S. Luo, "Preparation of highly monodisperse droplet in a t-junction microfluidic device," *AIChE Journal*, vol. 52, no. 9, pp. 3005–3010, Sep. 2006. DOI: 10.1002/aic.10924.

[36] A. Gupta and R. Kumar, "Effect of geometry on droplet formation in the squeezing regime in a microfluidic t-junction," *Microfluidics and Nanofluidics*, vol. 8, no. 6, pp. 799–812, Oct. 2009. DOI: 10.1007/s10404-009-0513-7.

[37] T. Glawdel, C. Elbuken, and C. L. Ren, "Droplet formation in microfluidic t-junction generators operating in the transitional regime. i. experimental observations," *Physical Review E*, vol. 85, no. 1, Jan. 2012. DOI: 10.1103/physreve.85.016322.

[38] G. F. Christopher, N. N. Noharuddin, J. A. Taylor, and S. L. Anna, "Experimental observations of the squeezing-to-dripping transition in t-shaped microfluidic junctions," *Physical Review E*, vol. 78, no. 3, Sep. 2008. DOI: 10.1103/physreve.78.036317.

[39] M. de Menech, P. Garsticki, F. Jousse, and H. A. Stone, “Transition from squeezing to dripping in a microfluidic t-shaped junction,” *Journal of Fluid Mechanics*, vol. 595, Jan. 2008. DOI: 10.1017/s002211200700910x.

[40] S. van Loo, S. Stoukatch, M. Kraft, and T. Gilet, “Droplet formation by squeezing in a microfluidic cross-junction,” *Microfluidics and Nanofluidics*, vol. 20, no. 10, Oct. 2016. DOI: 10.1007/s10404-016-1807-1.

[41] C. N. Baroud, F. Gallaire, and R. Dangla, “Dynamics of microfluidic droplets,” *Lab on a Chip*, vol. 10, no. 16, p. 2032, 2010. DOI: 10.1039/c001191f.

[42] B. Sandurkov, “Assay development for mangetic flow cytometry,” Master Thesis, TU München, 2018.

Statement

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Munich, December 4^{th}, 2020, Signature