Cover Page



Universiteit Leiden



The handle <u>http://hdl.handle.net/1887/37043</u> holds various files of this Leiden University dissertation

Author: Markešević, Nemanja Title: Optical properties of DNA-hosted silver clusters Issue Date: 2015-12-16

Bibliography

- M. B. Mohamed, V. Volkov, S. Link, and M. A. El-Sayed, *The 'lightning' gold nanorods: fluorescence enhancement of over a million compared to the gold metal*, Chem. Phys. Lett. **317**, 517 (2000).
- [2] A. Gaiduk, M. Yorulmaz, and M. Oritt, Correlated absorption and photoluminescence of single gold nanoparticles, ChemPhysChem 12, 1536 (2011).
- [3] M. Yorulmaz, S. Khatua, P. Zijlstra, A. Gaiduk, and M. Orrit, Luminescence quantum yield of single gold nanorods, Nano Lett. 12, 4385 (2012).
- [4] J. Walter, M.and Akola, O. Lopez-Acevedo, P. D. Jadzinsky, G. Calero, C. J. Ackerson, R. L. Whetten, H. Grönbeck, and H. Häkkinen, A unified view of ligand-protected gold clusters as superatom complexes, PNAS 105, 9157 (2008).
- [5] S. Raut, R. Chib, R. Rich, D. Shumilov, Z. Gryczynski, and I. Gryczynski, Polarization properties of fluorescent BSA protected Au₂₅ nanoclusters, Nanoscale 5, 3441 (2013).
- [6] J. Zheng and R. M. Dickson, Individual water-soluble dendrimer-encapsulated silver nanodot fluorescence, J. Am. Chem. Soc. 124, 13982 (2002).
- [7] H. Xu and K. S. Suslick, Sonochemical synthesis of highly fluorescent Ag nanoclusters, ACS Nano 4, 3209 (2010).
- [8] J. Yu, S. Patel, and R. Dickson, Invitro and intracellular production of peptideencapsulated fluorescent silver nanoclusters, Angew. Chem. 46, 2028 (2007).
- [9] D. Schultz and E. Gwinn, Stabilization of fluorescent silver clusters by RNA homopolymers and their DNA analogs: C,G versus A,T(U) dichotomy, Chem. Commun 47, 4715 (2011).
- [10] J. T. Petty, J. Zheng, N. V. Hud, and R. M. Dickson, DNA-templated Ag nanocluster formation, J. Am. Chem. Soc. 126, 5207 (2004).
- [11] L. Berti and G. A. Burley, Nucleic acid and nucleotide-mediated synthesis of inorganic nanoparticles, Nature Nanotechnology 3, 81 (2008).

- [12] S. M. Swasey, L. E. Leal, O. Lopez-Acevedo, J. Pavlovich, and E. G. Gwinn, *Silver (I) as DNA glue: Ag⁺-mediated guanine pairing revealed by removing Watson-Crick constraints*, Scientific Reports 5, 1 (2015).
- [13] E. G. Gwinn, P. O'Neill, A. J. Guerrero, D. Bouwmeester, and D. Fygenson, Sequence-dependent fluorescence of DNA-hosted silver nanoclusters, Adv. Mater. 20, 279 (2008).
- [14] W. Guo, J. Yuan, Q. Dong, and E. Wang, Highly sequence-dependent formation of fluorescent silver nanoclusters in hybridized DNA duplexes for single nucleotide mutation identification, J. Am. Chem. Soc. 132, 932 (2010).
- [15] J. M. Obliosca, C. Liu, and H.-C. Yeh, *Fluorescent silver nanoclusters as DNA probes*, Nanoscale 5, 8443 (2013).
- [16] W. Guo, J. Yuan, and E. Wang, Oligonucleotide-stabilized Ag nanoclusters as novel fluorescence probes for the highly selective and sensitive detection of the Hg²⁺, Chem. Commun. 23, 3395 (2009).
- [17] J. Yu, S. Choi, C. Richards, Y. Antoku, and R. Dickson, *Live cell surface label-ing with fluorescent Ag nanocluster conjugates*, Photochem. Photobiol. 84, 1435 (2008).
- [18] Y. Tao, E. Li, Z. Ju, J. Ren, and X. Qu, *One-step DNA-programmed growth of CpG conjugated silver nanoclusters: a potential platform for simultaneous enhanced immune response and cell imaging*, Chem. Commun. **49**, 6918 (2013).
- [19] D. Schultz, K. Gardner, S. S. R. Oemrawsingh, N. Markešević, K. Olsson, M. Debord, D. Bouwmeester, and E. Gwinn, *Evidence for rod-shaped DNA-stabilized silver nanocluster emitters*, Adv. Mater. 25, 2797 (2013).
- [20] S. S. R. Oemrawsingh, N. Markešević, E. G. Gwinn, E. R. Eliel, and D. Bouwmeester, Spectral properties of individual DNA-hosted silver nanoclusters at low temperatures, J. Phys. Chem. C 116, 25568 (2012).
- [21] S. M. Copp, D. Schultz, S. Swasey, J. Pavlovich, M. Debord, A. Chiu, K. Olsson, and E. Gwinn, *Magic numbers in DNA-stabilized fluorescent silver clusters lead to magic colors*, J. Phys. Chem. Lett. 5, 959 (2014).
- [22] E. B. Guidez and C. M. Aikens, *Theoretical analysis of the optical excitation spectra of silver and gold nanowires*, Nanoscale 4, 4190 (2012).
- [23] P. W. K. Rothemund, Folding DNA to create nanoscale shapes and patterns, Nature 440, 297 (2006).
- [24] D. Han, S. Pal, J. Nangreave, Z. Deng, Y. Liu, and H. Yan, DNA origami with complex curvatures in three-dimensional space, Science 332, 342 (2011).
- [25] I. H. Stein, V. Schüller, P. Böhm, P. Tinnefeld, and T. Liedl, Single-molecule FRET

ruler based on rigid DNA origami blocks, ChemPhysChem 12, 689 (2011).

- [26] R. Schreiber, J. Do, E.-M. Roller, T. Zhang, V. J. Schüller, P. C. Nickels, J. Feldmann, and T. Liedl, *Hierarchical assembly of metal nanoparticles, quantum dots and organic dyes using DNA origami scaffolds*, Nature Nanotechnology 9, 74 (2014).
- [27] X. Shen, A. Asenjo-Garcia, Q. Liu, Q. Jiang, F. J. G. de Abajo, N. Liu, and B. Ding, *Three-dimensional plasmonic chiral tetramers assembled by DNA origami*, Nano Lett. **13**, 2128 (2013).
- [28] A. Kuzyk, R. Schreiber, H. Zhang, A. O. Govorov, T. Liedl, and N. Liu, *Recon-figurable 3D plasmonic metamolecules*, Nature Materials 13, 862 (2014).
- [29] C. Zhou, X. Duan, and N. Liu, A plasmonic nanorod that walks on DNA origami, Nature Communications 9, 1 (2015).
- [30] Q. Zhang, Q. Jiang, N. Li, L. Dai, Q. Liu, L. Song, J. Wang, Y. Li, J. Tian, B. Ding, and Y. Du, DNA origami as an in vivo drug delivery vehicle for cancer therapy, ACS Nano 8, 6633 (2014).
- [31] S. Sellner, S. Kocabey, K. Nekolla, F. Krombach, T. Liedl, and M. Rehberg, DNA nanotubes as intracellular delivery vehicles in vivo, Biomaterials 53, 453 (2015).
- [32] P. O'Neill, P. W. K. Rothemund, A. Kumar, and D. K. Fygenson, *Sturdier DNA nanotubes via ligation*, Nano lett. **6**, 1379 (2006).
- [33] P. R. O'Neill, K. Young, D. Schiffels, and D. K. Fygenson, *Few-atom fluorescent silver clusters assemble at programmed sites on DNA nanotubes*, Nano Lett. 12, 5464 (2012).
- [34] P. Yin, R. F. Hariadi, S. Sahu, H. T. M. Choi, S. H. Park, T. H. LaBean, and J. H. Reif, *Programming DNA tube circumferences*, Science **321**, 824 (2008).
- [35] S. M. Copp, D. E. Schultz, S. Swasey, and E. G. Gwinn, Atomically precise arrays of fluorescent silver clusters: A modular approach for metal cluster photonics on DNA nanostructures, ACS Nano 9, 2303 (2015).
- [36] D. Schiffels, T. Liedl, and D. K. Fygenson, Nanoscale structure and microscale stiffness of DNA nanotubes, ACS Nano 7, 6700 (2013).
- [37] J. Zheng, P. R. Nicovich, and R. M. Dickson, *Highly Fluorescent Noble Metal Quantum Dots*, Annu. Rev. Phys. Chem. 58, 409431 (2007).
- [38] W. Harbich, S. Fedrigo, F. Meyer, D. Lindsay, J. Lignieres, J. Rivoal, and D. Kreisle, *Deposition of mass selected silver clusters in rare gas matrices*, J. Chem. Phys 93, 8535 (1990).
- [39] J. Tiggesbäumker, L. L. Köller, H. O. Lutz, and K. H. Meiwes-Broer, Giant resonances in silver-cluster photofragmentation, Chem. Phys. Lett. 190, 42 (1992).

- [40] C. Félix, C. Sieber, W. Harbich, J. Buttet, I. Rabin, W. Schulze, and G. Ertl, *Fluorescence and excitation spectra of Ag₄ in an argon matrix*, Chem. Phys. Lett. 313, 105 (1999).
- [41] C. Sieber, W. Buttet, J.and Harbich, C. Félix, R. Mitrić, and V. Bonačić-Koutecký, *Isomer-specific spectroscopy of metal clusters trapped in a matrix: Ag*₉, Phys. Rev. A **70**, 041201 (2004).
- [42] R. L. Whetten, J. T. Khoury, M. M. Alvarez, S. Murthy, I. Vezmar, Z. L. Wang, P. W. Stephens, C. L. Cleveland, W. D. Luedtke, and U. Landman, *Nanocrystal gold molecules*, Adv. Mater. 8, 428 (1996).
- [43] A. C. Templeton, W. P. Wuelfing, and R. W. Murray, *Monolayer-protected cluster molecules*, Acc. Chem. Res. 33, 27 (2000).
- [44] T.-H. Lee and R. M. Dickson, Single-molecule LEDs from nanoscale electroluminescent junctions, J. Phys. Chem. B 107, 7387 (2003).
- [45] X. Yang, M. Shi, R. Zhou, X. Chen, and H. Chen, Blending of HAuCl₄ and histidine in aqueous solution: a simple approach to the Au₁₀ cluster, Nanoscale 3, 2596 (2011).
- [46] S. Choi, R. Dickson, J. Lee, and J. Yu, Generation of luminescent noble metal nanodots in cell matrices, Photochem. Photobiol. Sci. 11, 274 (2012).
- [47] Z. Wu and R. Jin, On the ligands role in the fluorescence of gold nanoclusters, Nano Lett. 10, 2568 (2010).
- [48] M. S. Devadas, S. Bairu, H. Qian, E. Sinn, R. Jin, and G. Ramakrishna, *Temperature-dependent optical absorption properties of monolayer-protected Au*₂₅ and *Au*₃₈ clusters, J. Phys. Chem. Lett. 2, 2752 (2011).
- [49] C. I. Richards, S. Choi, J.-C. Hsiang, Y. Antoku, T. Vosch, A. Bongiorno, Y.-L. Tzeng, and R. M. Dickson, *Oligonucleotide-stabilized Ag nanocluster fluorophores*, J. Am. Chem. Soc. **130**, 5038 (2008).
- [50] B. Sengupta, K. Springer, J. G. Buckman, S. P. Story, O. H. Abe, Z. W. Hasan, Z. D. Prudowsky, S. E. Rudisill, N. N. Degtyareva, and J. T. Petty, DNA templates for fluorescent silver clusters and i-motif folding, J. Phys. Chem. C 113, 19518 (2009).
- [51] P. R. O'Neill, L. R. Velazquez, D. G. Dunn, E. G. Gwinn, and D. Fygenson, *Hairpins with poly-C loops stabilize four types of fluorescent Ag_n: DNA*, J. Phys. Chem. C **113**, 4229 (2009).
- [52] J. Sharma, H. Yeh, H. Yoo, J. Werner, and J. Martinez, A complementary palette of fluorescent silver nanoclusters, Chem. Commun. 46, 3280 (2010).
- [53] D. Schultz and E. G. Gwinn, Silver atom and strand numbers in fluorescent and

dark Ag:DNAs, Chem. Commun. 48, 5748 (2012).

- [54] K. Ma, Y. Shao, Q. Cui, F. Wu, S. Xu, and G. Liu, Base-stacking-determined fluorescence emission of DNA abasic site-templated silver nanoclusters, Langumir 28, 15313 (2012).
- [55] T. Li, L. Zhang, J. Ai, S. Dong, and E. Wang, *Ion-tuned DNA/Ag fluorescent nano-clusters as versatile logic device*, ACS Nano 5, 6334 (2011).
- [56] S. W. Yang and T. Vosch, Rapid detection of microRNA by a silver nanocluster DNA probe, Anal. Chem. 83, 6935 (2011).
- [57] S. A. Patel, M. Cozzuol, J. M. Hales, C. I. Richards, M. Sartin, J.-C. Hsiang, T. Vosch, J. W. Perry, and R. M. Dickson, *Electron transfer-induced blinking in Ag nanodot fluorescence*, J. Phys. Chem. C **113**, 20264 (2009).
- [58] K. Baishya, J. C. Idrobo, S. Öğüt, M. Yang, K. Jackson, and J. Jellinek, Optical absorption spectra of intermediate-size silver clusters from first principles, Phys. Rev. B 78, 075439 (2008).
- [59] J. Pacheco, R. Broglia, and B. Mottelson, *The intrinsic line width of the plasmon resonances in metal microclusters at very low temperatures: quantal surface fluctua-tions*, Z. Phys. D 21, 289 (1991).
- [60] G. Weick, R. A. Molina, D. Weinmann, and R. A. Jalabert, *Lifetime of the first and second collective excitations in metallic nanoparticles*, Phys. Rev. B 72, 115410 (2005).
- [61] G. Weick, G.-L. Ingold, R. A. Jalabert, and D. Weinmann, Surface plasmon in metallic nanoparticles: Renormalization effects due to electron-hole excitations, Phys. Rev. B 74, 165421 (2006).
- [62] J. Lermé, Size evolution of the surface plasmon resonance damping in silver nanoparticles: confinement and dielectric effects, J. Phys. Chem. C 115, 14098 (2011).
- [63] R. Fournier, Theoretical study of the structure of silver clusters, J. Chem. Phys. 115, 2165 (2001).
- [64] P. Yu, X. Wen, Y.-R. Toh, and J. Tang, *Temperature-dependent fluorescence in Au*₁₀ nanoclusters, J. Phys. Chem. C **116**, 6567 (2012).
- [65] V. Soto-Verdugo, H. Metiu, and E. G. Gwinn, *The properties of small Ag clusters bound to DNA bases*, J. Chem. Phys. **132**, 195102 (2010).
- [66] S. Krause, P. F. Aramendia, D. Tauber, and C. von Borczyskowski, *Freezing single molecule dynamics on interfaces and in polymers*, Phys. Chem. Chem. Phys. 13, 1754 (2011).
- [67] M. Hussels and M. Brecht, Effect of glycerol and PVA on the conformation of photo-

system I, Biochemistry 50, 3628 (2011).

- [68] Y. Zhang, S. Hartmann, and F. Moshary, *Fluorescence-line-narrowing spectroscopy* of nile blue in glass and polymer at 5 K: Determination of a single-site line shape function, J. Chem. Phys. **104**, 4371 (1996).
- [69] N. Verdal and A. M. Kelley, *Temperature dependence of phonon sidebands in line-narrowed fluorescence spectra of chromophores in glasses*, J. Chem. Phys. **118**, 7985 (2003).
- [70] R. Hildner, L. Winterling, U. Lemmer, U. Scherf, and J. Köhler, Single-molecule spectroscopy on a ladder-type conjugated polymer: electron-phonon coupling and spectral diffusion, ChemPhysChem 10, 2524 (2009).
- [71] P. Gruene, D. M. Rayner, B. Redlich, A. F. G. van der Meer, J. T. Lyon, G. Meijer, and A. Fielicke, *Structures of neutral Au*₇, *Au*₁₉, and *Au*₂₀ clusters in the gas phase, Science **321**, 674 (2008).
- [72] S. Kümmel, K. Andrae, and P. G. Reinhard, Collectivity in the optical response of small metal clusters, Appl. Phys. B 73, 293 (2001).
- [73] E. J. Heilweil and R. M. Hochstrasser, Nonlinear spectroscopy and picosecond transient grating study of colloidal gold, J. Chem. Phys. 82, 4762 (1985).
- [74] S. Fedrigo, W. Harbich, and J. Buttet, Optical response of Ag₂, Ag₃, Au₂, and Au₃ in argon matrices, J. Chem. Phys. 99, 5712 (1993).
- [75] W. Harbich, S. Fedrigo, and J. Buttet, *The optical absorption spectra of small silver clusters* (n=5-11) embedded in argon matrices, J. Chem. Phys. Lett. **195**, 613 (1992).
- [76] J. T. Petty, C. Fan, S. S. Story, B. Sengupta, A. S. J. Iyer, Z. Prudowsky, and R. M. Dickson, DNA encapsulation of ten silver atoms produces a bright, modulatable, near infrared-emitting cluster, J. Phys. Chem. Lett. 1, 2524 (2010).
- [77] J. P. Wilcoxon, J. E. Martin, F. Parsapour, B. Wiedenman, and D. F. Kalley, *Pho-toluminescence from nanosize gold clusters*, J. Chem. Phys. **108**, 9137 (1998).
- [78] A. Kuzyk, R. Schreiber, Z. Fan, G. Pardatscher, E. M. Roller, A. Högele, F. C. Simmel, A. O. Govorov, and T. Liedl, DNA-based self-assembly of chiral plasmonic nanostructures with tailored optical response, Nature 483, 311 (2012).
- [79] I. Chakraborty, S. Bag, U. Landman, and T. Pradeep, Atomically precise silver clusters as new SERS substrates, J. Phys. Chem. Lett. 4, 2769 (2013).
- [80] D. Schultz, S. M. Copp, N. Markešević, K. Gardner, S. S. R. Oemrawsingh, D. Bouwmeester, and E. Gwinn, *Dual-color nanoscale assemblies of structurally stable, few-atom silver clusters, as reported by fluorescence resonance energy transfer,* ACS Nano 7, 9798 (2013).

- [81] J. Yan and S. Gao, Plasmon resonances in linear atomic chains: Free-electron behavior and anisotropic screening of d electrons, Phys. Rev. B 78, 235413 (2008).
- [82] A. Ojanperä, M. J. Puska, and O. Lopez-Acevedo, First-principles study of excited state evolution in a protected gold complex, J. Phys. Chem. C 117, 11837 (2013).
- [83] M. Zhou, S. Vdović, S. Long, M. Zhu, L. Yan, Y. Wang, Y. Niu, X. Wang, Q. Guo, R. Jin, and A. Xia, *Intramolecular charge transfer and solvation dynamics of thiolateprotected Au*₂₀(*SR*)₁₆ *clusters studied by ultrafast measurement*, J. Phys. Chem. A **117**, 10294 (2013).
- [84] F. Güttler, J. Sepiol, T. Plakhotnik, A. Mitterdorferr, A. Renn, and U. P. Wild, Single molecule spectroscopy - fluorescennce excitation spectra with polarized light, J. Lumin. 56, 29 (1993).
- [85] F. Güttler, M. Croci, A. Renn, and U. P. Wild, Single molecule polarization spectroscopy: pentacene in p-terphenyl, Chem. Phys. 211, 421 (1996).
- [86] T. Ha, T. Enderle, D. S. Chemla, P. R. Selvin, and S. Weiss, Single molecule dynamics studied by polarization modulation, Phys. Rev. Let. 77, 3979 (1996).
- [87] S. A. Empedocles, R. Neuhauser, K. Shimizu, and M. G. Bawendi, *Photolumi-nescence from single semiconductor nanostructures*, Adv. Mater. **11**, 1243 (1999).
- [88] T. Ha, T. A. Laurence, D. S. Chemla, and S. Weiss, *Polarization spectroscopy of single fluorescent molecules*, J. Phys. Chem. B 103, 6839 (1999).
- [89] A. Tcherniak, S. Dominguez-Medina, W.-S. Chang, P. Swanglap, L. S. Slaughter, C. F. Landes, and S. Link, One-photon plasmon luminescence and its application to correlation spectroscopy as a probe for rotational and translational dynamics of gold nanorods, J. Phys. Chem. C 115, 15938 (2011).
- [90] W.-S. Chang, J. W. Ha, L. S. Slaughter, and S. Link, *Plasmonic nanorod absorbers* as orientation sensors, PNAS 107, 2781 (2010).
- [91] C. Sönnichsen, T. Franzl, T. Wilk, G. von Plessen, J. Feldmann, O. Wilson, and P. Mulvaney, *Drastic reduction of plasmon damping in gold nanorods*, Phys. Rev. Lett. 88, 077402 (2002).
- [92] O. L. Muskens, G. Bachelier, N. D. Fatti, F. Valle, A. Brioude, X. Jiang, and M.-P. Pileni, *Quantitative absorption spectroscopy of a single gold nanorod*, J. Phys. Chem. C 112, 8917 (2008).
- [93] K. Becker, E. Da Como, J. Feldmann, F. Scheliga, E. Thorn Csányi, S. Tretiak, and J. M. Lupton, *How chromophore shape determines the spectroscopy of phenylenevinylenes: origin of spectral broadening in the absence of aggregation*, J. Phys. Chem. B **112**, 4859 (2008).
- [94] J. M. Lupton, Chromophores in conjugated polymers all straight?, ChemPhys-

Chem 13, 901 (2012).

- [95] O. Schubert, J. Becker, L. Carbone, Y. Khalavka, T. Provalska, I. Zins, and C. Sönnichsen, *Mapping the polarization pattern of plasmon modes reveals nanoparticle symmetry*, Nano Lett. 8, 2345 (2008).
- [96] M. P. Busson, B. Rolly, B. Stout, N. Bonod, and S. Bidault, Accelerated single photon emission from dye molecule-driven nanoantennas assembled on DNA, Nature Communications 3, 1 (2012).
- [97] M. P. Busson, B. Rolly, B. Stout, N. Bonod, E. Larquet, A. Polman, and S. Bidault, Optical and topological characterization of gold nanoparticle dimers linked by a single DNA double strand.
- [98] H.-C. Yeh and I.-M. V. D. M. J. W. J. Sharma, J.and Shih, A fluorescence light-up Ag nanocluster probe that discriminates single-nucleotide variants by emission color, J. Am. Chem. Soc. 134, 11550 (2012).
- [99] N. Markešević, S. S. R. Oemrawsingh, D. Schultz, E. G. Gwinn, and D. Bouwmeester, *Polarization Resolved Measurements of Individual DNA-Stabilized Silver Clusters*, Adv. Optical Mater. 2, 765 (2014).
- [100] Z. Yuan, Y.-C. Chen, H.-W. Li, and H.-T. Chang, *Fluorescent silver nanoclusters stabilized by DNA scaffolds*, Chem. Commun. 50, 9800 (2014).
- [101] E. Gwinn, D. Schultz, S. M. Copp, and S. Swasey, DNA-protected silver clusters for nanophotonics, Nanomaterials 5, 180 (2015).
- [102] T. Driehorst, P. O'Neill, P. M. Goodwin, S. Pennathur, and D. K. Fygenson, Distinct conformations of DNA-stabilized fluorescent silver nanoclusters revealed by electrophoretic mobility and diffusivity measurements, Langmuir 27, 8923 (2011).
- [103] T. L. Jennings, M. P. Singh, and G. F. Strouse, *Fluorescent lifetime quenching near* d = 1.5 nm gold nanoparticles: probing NSET validity, J. Am. Chem. Soc. **128**, 5462 (2006).
- [104] M. P. Busson and S. Bidault, Selective excitation of single molecules coupled to the bright mode of a plasmonic cavity, Nano Lett. 14, 284 (2014).
- [105] E. N. Hooley, V. Paolucci, Z. Liao, M. R. Carro Temboury, and T. Vosch, Singlemolecule characterization of near-infrared-emitting silver nanoclusters, Adv. Optical Mater. 3, 1109 (2015).
- [106] C. A. Mirkin, R. L. Letsinger, R. C. Mucic, and J. J. Storhoff, A DNA-based method for rationally assembling nanoparticles into macroscopic materials, Nature 382, 607 (1996).
- [107] B. Bharti, G. H. Findenegg, and O. D. Velev, Analysis of the field-assisted permanent assembly of oppositely charged particles, Langmuir 30, 6577 (2014).

- [108] M. E. Leunissen, R. Dreyfus, F. C. Cheong, D. G. Grier, R. Sha, N. C. Seeman, and P. M. Chaikin, *Switchable self-protected attractions in DNA-functionalized colloids*, Nature Mat. 8, 590 (2009).
- [109] S. Y. Kim, S.-H.and Lee, G.-R. Yi, D. J. Pine, and S.-M. Yang, *Microwave-assisted self-organization of colloidal particles in confining aqueous droplets*, J. Am. Chem. Soc. **128**, 10897 (2006).
- [110] A. B. Pawar and I. Kretzschmar, *Fabrication, assembly, and application of patchy particles*, Macromol. Rapid Commun. **31**, 150 (2010).
- [111] F. Smallenburg, H. R. Vutukuri, A. Imhof, A. van Blaaderen, and M. Dijkstra, Self-assembly of colloidal particles into strings in a homogeneous external electric or magnetic field, J. Phys.: Condens. Matter 24, 464113 (2012).
- [112] R. Dreyfus, M. E. Leunissen, R. Sha, A. V. Tkachenko, N. C. Seeman, D. J. Pine, and P. M. Chaikin, *Simple quantitative model for the reversible association of DNA coated colloids*, Phys. Rev. Lett. **102**, 048301 (2009).