APEM journal

Advances in Production Engineering & Management
Volume 15 | Number 3 | September 2020 | pp 358–368
https://doi.org/10.14743/apem2020.3.371

ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Testing of novel nano gold ink for inkjet printing

Rudolf, R.[a,b,*], **Majerič, P.**[a,b], **Golub, D.**[a], **Tiyyagura, H.R.**[a]

[a]University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia
[b]Zlatarna Celje d.o.o., Celje, Slovenia

ABSTRACT

Gold nanoparticles (GNPs) were synthesised by the Ultrasonic Spray Pyrolysis (USP) process and collected in deionised water with the addition of a stabiliser, i.e. PVP (0.1 wt.%). With the use of a rotary evaporator, a highly concentrated GNPs' suspension was achieved (600 ppm concentration of GNPs), which was used directly as novel nano gold ink for inkjet printing. The physical and chemical characteristics of such prepared nano gold ink were explained in detail by the use of Zeta (ζ) Potential, ATR-FTIR spectroscopy, UV/VIS spectroscopy, and nanoparticle size was identified through SEM. With nano gold ink the chosen pattern was printed onto photo paper, which was characterised for confirming the presence of gold with optical and SEM/EDX observations. The observations revealed that the tested printed nano gold ink on the paper provided a new route for the fabrication of paper-based electrochemical immunosensors, colorimetric sensors and nano-metallic biomedical sensors.

ARTICLE INFO

Keywords:
Inkjet printing;
Nano gold ink;
Gold nanoparticles;
Characterisation;
Paper-based sensor

**Corresponding author:*
rebeka.rudolf@um.si
(Rudolf, R.)

Article history:
Received 7 August 2020
Revised 9 September 2020
Accepted 14 September 2020

References

[1] Parab, H.J., Chen, H.M., Bagkar, N.C., Liu, R.-S., Hwu, Y.-K., Tsai, D.P. (2010). Approaches to the synthesis and characterization of spherical and anisotropic noble metal nanomaterials, *Nanotechnologies for the Life Sciences,* Vol. 1, 405-459, doi: 10.1002/9783527610419.ntls0133.

[2] Singh, A., Gautam, P.K., Verma, A., Singh, V., Shivapriya, P.M., Shivalkar, S., Sahoo, A.K., Samanta, S.K. (2020). Green synthesis of metallic nanoparticles as effective alternatives to treat antibiotics resistant bacterial infections: A review, *Biotechnology Reports*, Vol. 25, Article No. e00427, doi: 10.1016/j.btre.2020.e00427.

[3] Barberio, M., Giusepponi, S., Vallières, S., Scisció, M., Celino, M., Antici, P. (2020). Ultra-fast high-precision metallic nanoparticle synthesis using laser-accelerated protons, *Scientific Reports*, Vol. 10, No. 1, Article No. 9570, doi: 10.1038/s41598-020-65282-9.

[4] Yaqoob, S.B., Adnan, R., Rameez Khan, R.M., Rashid, M. (2020). Gold, silver, and palladium nanoparticles: A chemical tool for biomedical applications, *Frontiers in Chemistry,* Vol. 8, Article No. 376, doi: 10.3389/fchem.2020.00376.

[5] Rudolf, R., Popović, D., Tomić, S., Bobovnik, R., Lazić, V., Majerič, P., Anžel, I., Čolić, M. (2020). Microstructure characterisation and identification of the mechanical and functional properties of a new PMMA-ZnO composite, *Materials*, Vol. 13, No. 12, Article No. 2717, doi: 10.3390/ma13122717.

[6] Kuppe, C., Rusimova, K.R., Ohnoutek, L., Slavov, D., Valev, V.K. (2020). "Hot" in plasmonics: Temperature-related concepts and applications of metal nanostructures, *Advanced Optical Materials,* Vol. 8, No. 1, Article No. 1901166, doi: 10.1002/adom.201901166.

[7] Shafiq, M., Anjum, S., Hano, C., Anjum, I., Abbasi, B.H. (2020). An overview of the applications of nanomaterials and nanodevices in the food industry, *Foods*, Vol. 9, No. 2, Article No.148, doi: 10.3390/foods9020148.

[8] Maleki, H., Bertola, V. (2020). Recent advances and prospects of inkjet printing in heterogeneous catalysis, *Catalysis Science & Technology,* Vol. 10, No. 10, 3140-3159, doi: 10.1039/D0CY00040J.

[9] Tan, H.W., An, J., Chua, C.K., Tran, T. (2019). Metallic nanoparticle inks for 3D printing of electronics, *Advanced Electronic Materials,* Vol. 5, No. 5, Article No. 1800831, doi: 10.1002/aelm.201800831.

[10] Cano-Raya, C., Denchev, Z.Z., Cruz, S.F., Viana, J.C. (2019). Chemistry of solid metal-based inks and pastes for printed electronics – A review, *Applied Materials Today,* Vol. 15, 416-430, doi: 10.1016/j.apmt.2019.02.012.

[11] Calvert, P. (2001). Inkjet printing for materials and devices, *Chemistry of Materials,* Vol. 13, No. 10, 3299-3305, doi: 10.1021/cm0101632.
[12] Derby, B. (2010). Inkjet printing of functional and structural materials: Fluid property requirements, feature stability, and resolution, *Annual Review of Materials Research,* Vol. 40, No. 1, 395-414, doi: 10.1146/annurev-matsci-070909-104502.
[13] Cruz, B., Albrecht, A., Eschlwech, P., Biebl, E. (2019). Inkjet printing of metal nanoparticles for green UHF RFID tags, *Advances in Radio Science,* Vol. 17, 119-127, doi: 10.5194/ars-17-119-2019.
[14] Karim, N., Afroj, S., Tan, S., Novoselov, K.S., Yeates, S.G. (2019). All inkjet-printed graphene-silver composite ink on textiles for highly conductive wearable electronics applications, *Scientific Reports,* Vol. 9, No. 1, Article No. 8035, doi: 10.1038/s41598-019-44420-y.
[15] Soleimani-Gorgani, A. (2016). 14 – Inkjet Printing, In Izdebska, J., Thomas, S. (eds.), *Printing on Polymers*, William Andrew Publishing, New York, USA, 231-246, doi: 10.1016/B978-0-323-37468-2.00014-2.
[16] Chu, J.-H., Joo, S.-J., Kim, H.-S. (2019). Development of a via-hole connection process via intense pulsed light sintering with Cu micro/Ag nano-hybrid ink for a multi-layered flexible printed circuit board, *Thin Solid Films,* Vol. 680, 1-11, doi: 10.1016/j.tsf.2019.04.015.
[17] Bishop, P.T., Ashfield, L.J., Berzins, A., Boardman, A., Buche, V., Cookson, J., Gordon, R.J., Salcianu, C., Sutton, P.A. (2010). Printed gold for electronic applications, *Gold Bulletin,* Vol. 43, No. 3, 181-188, doi: 10.1007/BF03214985.
[18] Deng, M., Zhang, X., Zhang, Z., Xin, Z., Song, Y. (2014). A gold nanoparticle ink suitable for the fabrication of electrochemical electrode by inkjet printing, *Journal of Nanoscience and Nanotechnology,* Vol. 14, No. 7, 5114-5119, doi: 10.1166/jnn.2014.7208.
[19] Su, C.-H., Chiu, H.-L., Chen, Y.-C., Yesilmen, M., Schulz, F., Ketelsen, B., Vossmeyer, T., Liao, Y.-C. (2019). Highly responsive PEG/gold nanoparticle thin-film humidity sensor via inkjet printing technology, *Langmuir,* Vol. 35, No. 9, 3256-3264, doi: 10.1021/acs.langmuir.8b03433.
[20] Bacalzo Jr., N.P., Go, L.P., Querebillo, C.J., Hildebrandt, P., Limpoco, F.T., Enriquez, E.P. (2018). Controlled microwave-hydrolyzed starch as a stabilizer for green formulation of aqueous gold nanoparticle ink for flexible printed electronics, *ACS Applied Nano Materials,* Vol. 1, No. 3, 1247-1256, doi: 10.1021/acsanm.7b00379.
[21] Pavithra, M., Muruganand, S., Parthiban, C. (2018). Development of novel paper based electrochemical immunosensor with self-made gold nanoparticle ink and quinone derivate for highly sensitive carcinoembryonic antigen, *Sensors and Actuators B: Chemical*, Vol. 257, 496-503, doi: 10.1016/j.snb.2017.10.177.
[22] Golub, D., Ivanič, A., Majerič, P., Tiyyagura, H.R., Anžel, I., Rudolf, R. (2019). Synthesis of colloidal Au nanoparticles through ultrasonic spray pyrolysis and their use in the preparation of polyacrylate-AuNPs' composites, *Materials*, Vol. 12, No. 22, Article No. 3775, doi: 10.3390/ma12223775.
[23] Rudolf, R., Shariq, M., Veselinovic, V., Adamovic, T., Bobovnik, R., Kargl, R., Majeric, P. (2018). Synthesis of gold nanoparticles through ultrasonic spray pyrolysis and its application in printed electronics, *Contemporary Materials,* Vol. 9, No. 1, 106-112.
[24] Shariq, M., Marić, N., Gorše, G.K., Kargl, R., Rudolf, R. (2018). Synthesis of gold nanoparticles with ultrasonic spray pyrolysis and its feasibility for ink-jet printing on paper, *Micro and Nanosystems*, Vol. 10, No. 2, 102-109, doi: 10.2174/1876402910666180802113859.
[25] Shariq, M., Friedrich, B., Budic, B., Hodnik, N., Ruiz-Zepeda, F., Majerič, P., Rudolf, R. (2018). Successful synthesis of gold nanoparticles through ultrasonic spray pyrolysis from a gold(III) nitrate precursor and their interaction with a high electron beam, *ChemistryOpen*, Vol. 7, No. 7, 533-542, doi: 10.1002/open.201800101.
[26] Shariq, M., Majerič, P., Friedrich, B., Budic, B., Jenko, D., Dixit, A.R., Rudolf, R. (2017). Application of gold(III) acetate as a new precursor for the synthesis of gold nanoparticles in PEG through ultrasonic spray pyrolysis, *Journal of Cluster Science,* Vol. 28, No. 3, 1647-1665, doi: 10.1007/s10876-017-1178-0.
[27] Kumar, A., Dixit, C.K. (2017). 3 - Methods for characterization of nanoparticles, In: Nimesh, S., Chandra, R., Gupta, N., (eds.), *Advances in nanomedicine for the delivery of therapeutic nucleic acids*, Woodhead Publishing, Cambridge, United Kingdom, 43-58, doi: 10.1016/B978-0-08-100557-6.00003-1.
[28] Chirayil, C.J., Abraham, J., Mishra, R.K., George, S.C., Thomas, S. (2017). Chapter 1 – Instrumental techniques for the characterization of nanoparticles, In: Thomas, S., Thomas, R., Zachariah, A.K., Mishra, R.K. (eds.), In: *Thermal and rheological measurement techniques for nanomaterials characterization, micro and nano technologies*, Elsevier, Amsterdam, Netherlands, 1-36, doi: 10.1016/B978-0-323-46139-9.00001-3.
[29] Das, T., Kolli, V., Karmakar, S., Sarkar, N. (2017). Functionalisation of polyvinylpyrrolidone on gold nanoparticles enhances its anti-amyloidogenic propensity towards hen egg white lysozyme, *Biomedicines*, Vol. 5, No. 2, Article No. 19, doi: 10.3390/biomedicines5020019.
[30] Dhumale, V.A., Gangwar, R.K., Datar, S.S., Sharma, R.B. (2012). Reversible aggregation control of polyvinylpyrrolidone capped gold nanoparticles as a function of pH, *Materials Express*, Vol. 2, No. 4, 311-318, doi: 10.1166/mex.2012.1082.
[31] Amendola, V., Meneghetti, M. (2009). Size evaluation of gold nanoparticles by UV−vis spectroscopy, *The Journal of Physical Chemistry C,* Vol. 113, No. 11, 4277-4285, doi: 10.1021/jp8082425.
[32] Tiyyagura, H.R., Majerič, P., Anžel, I., Rudolf, R. (2020). Low-cost synthesis of AuNPs through ultrasonic spray pyrolysis, *Materials Research Express,* Vol. 7, No. 5, Article No. 055017, doi: 10.1088/2053-1591/ab80ea.
[33] Lin, P.-C., Lin, S., Wang, P.C., Sridhar, R. (2014). Techniques for physicochemical characterization of nanomaterials, *Biotechnology Advances.,* Vol. 32, No. 4, 711-726, doi: 10.1016/j.biotechadv.2013.11.006.
[34] Shariq, M., Chattopadhyaya, S., Rudolf, R., Rai Dixit, A. (2020). Characterization of AuNPs based ink for inkjet printing of low cost paper based sensors, *Materials Letters*, Vol. 264, Article No. 127332, doi: 10.1016/j.matlet.2020.127332.

[35] Cortie, M. (2011). Technological applications of gold nanoparticles, In: Louis, C., Pluchery, O. (eds.), *Gold nanoparticles for physics, chemistry and biology*, Imperial College Press, London, United Kingdom, 355-377, doi: 10.1142/9781848168077_0013.