A Nano Factory: From 3D Prints to Sensing Chips

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Rapid prototyping of nanoscale sensing devices is of paramount importance to many emerging application-spaces which require portable analysis, in the field, factory, or away from the clinic. However, full-chain for chip manufacture – schemes comprising nano- and microscale lithography, chip dicing, robotics for accurate picking-and-placing, device packaging, as well as the sensor test measurements – are often confined to industry settings rather than research environments thus hampering the ability to quickly iterate novel designs.

Within our newly established Smart Nano NI laboratory in Queen's Physics Department, we have established processes towards the fabrication, manipulation and testing of nanostructured sensing chips for surface enhanced Raman spectroscopy (SERS) sensing – chips that use the Raman effect, a highly selective analytical spectroscopy commonly described as a 'molecular fingerprint' that can be enhanced to single-molecule level by large electric fields generated by collective electron oscillations near certain metals.

In the current study we demonstrate the reduction of chip areas to 2mm×2mm via dicing saw, and their accurate placement and packaging via precise robotics and 3D printed parts. Further, quality control through machine vision and AI techniques has been investigated where small inter-chip imperfections may be identified [1]. Final chip designs demonstrated a confinement of applied solution (micropipette) of a target molecule for optimum pre-concentration, and thus analytical sensitivity, especially important where solution-substrate interaction is hydrophilic [1]. Signal enhancement of up to 10^6× and uniformity (relative standard deviation) of 10% have been recorded. The study thus paves the way for the rapid development of highly sensitive and reproducible sensors, of relevance to a broad range of application areas where portable detection is required [2,3].

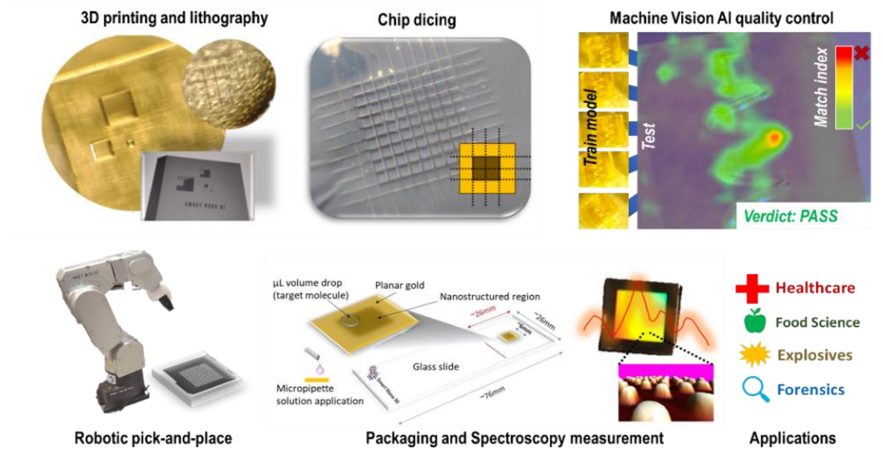

Figure 1. Smart Nano NI process for rapid development of nano-sensors

[1] Hardy M, Chu HOM, Pauly S, Bowman RM et al. White Light Transmission Spectroscopy for Rapid Quality Control Imperfection Identification in Nanoimprinted Surface-Enhanced Raman Spectroscopy Substrates. *ACS Meas. Sci. Au* 2025, **5**, 2, 250–263
[2] Hardy M & Chu HOM. Laser wavelength selection in Raman spectroscopy. *Analyst* 2025, **150**, 1986-2008
[3] Hardy M & Goldberg Oppenheimer P. 'When is a Hotspot a Good Nanospot' *Nanoscale* 2024, **16**, 3293-3323

Mike Hardy is an interdisciplinary scientist having worked within Physics, Chemical Engineering, and Biological Sciences. His background is in Physics, with foci in spectroscopy, specifically surface-enhanced Raman spectroscopy (SERS), custom-built optics, and condensed matter physics. Mike completed his BSc and PhD in Physics at Queen's University Belfast under the supervision of Dr Paul Dawson, studying asymmetric (Fano) resonances for quantitative SERS, and collaborating with Airbus Group Innovations (Munich, DE) on the EU-funded, Bomb Factory Detection by Networks of Advanced Sensors (BONAS) project. He is currently part of the new Smart Nano NI Project at Queen's, led by Prof. Robert M. Bowman. His activities within Smart Nano have moved into micro-engineering and optical device design, frequently liaising with nanotech/photonics-based partner companies Yelo, Cirdan Imaging, and Causeway Sensors. His other interests include fundamental studies in theoretical-experimental SERS comparisons, wider plasmonics and nano-photonics research, and more recently, the standardisation of Raman data/devices, and use of machine learning within spectroscopy. He is a supporter of technology transfer activities within universities and a graduate from the University of Birmingham's Medici Enterprise Training Programme. Mike is also a passionate advocate for cooperation across the sciences and is keen to establish strong collaborative activities between leading research groups.

Awards:

Electro Optics Frontiers Innovation Award 2025 Shortlist (Europa Science Ltd)

Top 40 author (Most Popular Articles) in Nanoscale Journal 2024 (Royal Society of Chemistry)

Royal Society of Chemistry Skinner Prize at Faraday Discussion on Nanoplasmonics, London, UK

Memberships:

Institute of Physics (UK): Member of Medical Physics, Nanoscale Physics and Technology, Materials and Characterisation, Thin Films and Surfaces, Optical Group

Infrared and Raman Discussion Group (UK): Member

Virtual Institute for Data Intensive Research (VIDIR) @ School of Mathematics and Physics, Queen's University Belfast, UK: Member

Recent conference Talks:

[1] Hardy M. **'Data, data everywhere… but what to do with it?' / Smart Nano NI, Shining Light on Irish Photonics.** UCD Spotlight Event, University College Dublin, Dublin, Ireland, May 30 2025 [Invited talk]

[2] Hardy M, Chu HOM, Hill BJF, Bowman RM et al. **Shining Light on Imperfection in Nanoimprint Lithography: Nanodome Surface enhanced Raman spectroscopy for SARS-CoV2 Nasal Spray Detection.** Biosensing III Session: International Conference on Raman Spectroscopy XXVIII (ICORS24), Rome, Italy. Aug 1 2024 [Contributed talk]

Recent poster presentations:

[1] Hardy M, Wiggins J & Bowman RM **Custom-built spectroscopy systems at Smart Nano.** 2nd Annual Computer Vision @ Queen's Symposium, Belfast, UK. July 18, 2024 [Contributed poster]

[2] Grady A, Barnes D, Hardy M, Kanade P, Moradiani F, Wiggins J, & Bowman RM. **3D Printing Mathematical Objects.** Queen's University Mathematics Student Showcase Autumn 2024, Belfast, UK [Contributed poster]

Selected peer reviewed journal papers:

[1] Hardy M & Chu HOM 2025 **Laser Wavelength Selection in Raman Spectroscopy.** *The Analyst* 150, 1986-2008

[2] Hardy M, Chu HOM, Pauly S, Cavanagh KF, Hill BJF, Wiggins J, Schilling A, Scott JN, Doherty MD, McCarron R, Goldberg Oppenheimer P, Grover LM, Hendren WR, Winfield RJ, Dawson P & Bowman RM. 2025 **White light transmission spectroscopy for Imperfection Identification in Nanoimprinted Surface Enhanced Raman Spectroscopy Substrates.** *ACS Meas. Sci. Au* 5(2) 250-263

[3] Hardy M & Goldberg Oppenheimer P. **'When is a hotspot a good nanospot' – review of analytical and hotspot-dominated surface enhanced Raman spectroscopy nanoplatforms.** *Nanoscale* 2024 16 3293-3323

[4] Stokes K, Clarke K, Odetade D, Hardy M & Goldberg Oppenheimer P. 2023 **Advances in lithographic techniques for precision nanostructure fabrication in biomedical applications**. *Discover Nano* 18 153