FY2023 Annual Report

Light-Matter Interactions for Quantum Technologies Unit
Professor Síle Nic Chormaic

Abstract

In FY2023, we continued to grow our international network of collaborators and produce many exciting results on our nanofibre applictions work in cold and Rydberg atoms, and as manipulators for anisotropic particles. We also progressed extremely well in the trapping of the "very small" using plasmonic metamaterial devices designed in-house. Our major research outputs are discussed below and included the completion of two PhD theses in the unit. We also continued to contribute to outreach activities through the OSA and SPIE Student Chapters and welcomed many young research interns from all around the world to hone their research skills by spending time with us here at OIST.

1. Staff

Research Staff

- Dr. Dylan Brown, Postdoctoral Scholar
- Dr. Fathy Hassan, OIST Interdisciplinary Postdoc with pi-Conjugated Polymers Unit (Lecturer, Tanta University, Egypt)
- Dr. Shilong Li, Staff Scientist (until November 2023)
- Dr Wenfang Li, Staff Scientist
- Dr Ramgopal Madugani, Postdoctoral Scholar
- Dr Souvik Sil, Postdoctoral Scholar

- Dr. Viet Giang Truong, Group Leader/Staff Scientist

Support Staff

- Dr. Kristoffer Karlsson, Technician
- Emi Nakamura, Research Unit Administrator
- Metin Ozer, Technician

PhD Students

- Sergei Abdrakhmanov, OIST PhD student (from January 2024)
- Hania Altabbaa, OIST PhD student (from January 2024)
- Samuel Begumya, OIST PhD student (from September 2023)
- Theodoros Bouloumis, OIST PhD student (until Dec 2023)
- Mohammed Zia Jalaludeen, OIST PhD student
- Amal Jose, OIST PhD student (from May 2023)
- Pramitha Praveen Kamath, OIST PhD student
- Maki Maeda, OIST PhD student (until March 2024)
- Aswathy Raj, OIST PhD student
- Zohreh Shahrabifarahani, OIST PhD student
- Alexey Vylegzhanin, OIST PhD student

Rotation/Intern Students/Visiting Research Student

- Matthew Peters, Visiting Student, University of Victoria, Canada (March 2024)
- Veronika Giricz, Visiting Research Student, Universitaet Stuttgart, Germany (November 2023 - May 2024)
- Guillermo Perez Lobato, Research Intern, Research and Advanced Studies Centre of the IPN, Mexico (October 2023 - March 2024)
- Tom Rodemund, Visiting Research Student (remote), TU Chemnitz, Germany (October 2023 - September 2024)
- Lunnet Newman Yokomizo, Research Intern, Ecole Polytechnique, Paris, France (June - August 2023)
- Anna Kortel, Research Intern, Russia (May 2023 - April 2024)
- German Suslin, Research Intern, Far Eastern Federal University, Russia (May 2023 - April 2024)
- Matthew Deonarine, Visiting Research Student, Toronto Metropolitan University, Canada (March - April 2023)
- Amal Jose, Rotation Student (January – April 2023)
- Jia Jun Chen, Research Intern (November 2022 – April 2023)
- Sergei Abdrakhmanov, Research Intern (October 2022 – April 2023)
- Aleksandr Zaitsev, Research Intern (June 2022 – June 2023)
- Liming Mao, Visiting Research Student, Harbin Engineering University, China (June 2022 – June 2023)

- Zhuowei Cheng, Visiting Research Student, Harbin Engineering University, China (June 2022 – June 2023)
- Maryna Khrypko, OIST Foundation Research Intern (June 2022 – August 2023)

Visiting Researcher/JSPS Invitational Fellow

- Prof. Reuven Gordon, JSPS Invitation Fellowship, University of Victoria, Canada (March 2024)
- Dr Kyu-Ri Choi, Chungbuk National University, Republic of Korea, (July - August 2023)
- Bin-Chan Joo, Chungbuk National University, Republic of Korea (July - August 2023)
- Dr Yanqiu Du, Visiting Researcher, Harbin Engineering University and Heilongjiang University of Science and Technology, China (May 2022 – May 2023)
- Prof Domna Kotsifaki, Duke Kunshan University, China
- Dr Ke Tian, Harbin Engineering University, China
- Dr Aysen Gurkan Ozer, Visiting Researcher (May 2023 - March 2024)

2. Collaborations

- **Theme: Plasmonic trapping of nanoparticles**
    - Type of collaboration: Joint research
    - Researchers:
        - D. Kotsifaki (Duke Kunshan University, China)

- **Theme: Nano-imaging techniques**
    - Type of collaboration: Joint research
    - Researchers:
        - YU Lee (Chungbuk National University, South Korea)

- **Theme: Transverse spin effects**
    - Type of collaboration: Joint research
    - Researchers:
        - M. Petrov (ITMO, Russia)
        - I. Toftul (ANU, Australia)
        - G. Tkachenko (Tokyo University of Science, Japan)

- **Theme: Imaging of WGM resonators**
    - Type of collaboration: Joint research
    - Researchers:
        - K. Tian (Harbin Engineering University, China)

- **Theme: Rydberg atom excitation using optical nanofibres**
    - Type of collaboration: Joint research
    - Researchers:

        - K. Moelmer (Niels Bohr Institute, Denmark)
        - J. Robert (ENS Paris Saclay, France)
        - E. Brion (University of Toulouse, France)
        - D. Kornovan (Aarhus University, Denmark)

- **Theme: Nonlinear materials for WGM resonators**
    - Type of collaboration: Joint research
    - Researchers:
        - P. Wang (Harbin Engineering University, China)
        - K. Tian (Harbin Engineering University, China)

- **Theme: Plasma in microbubble cavities**
    - Type of collaboration: Joint research
    - Researchers:
        - T. Carmon (Technion, now Tel-Aviv University, Israel)

- **Theme: E-coli detection**
    - Type of collaboration: Joint research
    - Researchers:
        - D. Kotsifaki (Duke Kunshan Univesity, China)
        - R. R. Singh (Information Processing Biology Unit, OIST)

- **Theme: Neutral atoms and optical nanofibres**
    - Type of collaboration: Joint research
    - Researchers:
        - T. Busch (Quantum Systems Unit, OIST)
        - D. Kornovan (Aarhus University, Denmark)

3. Activities and Findings

3.1 Excitation of 87Rb Rydberg atoms to nS and nD states (n<68) via an optical nanofiber

Cold Rydberg atoms are a promising platform for quantum technologies, and combining them with optical waveguides has the potential to create robust quantum information devices. In this work, we have achieved excitation of cold ^{87}Rb Rydberg atoms next to an ONF via two-photon excitation to a range of $n\mathrm{S}_{1/2}$, $n\mathrm{D}_{3/2}$, and $n\mathrm{D}_{5/2}$ Rydberg states with n ranging from 24 to 68. We have also measured the excitation spectrum, the resonant dip position, and MOT loss rate dependence on the principal quantum number, see Fig. 1. We observed a strong red shift of the $\mathrm{S}_{1/2}$ states that was not detected with the nD states. This result suggests that, for future work, the nD states, particularly the $n\mathrm{D}_{5/2}$ states, are the most suitable for ONF-based Rydberg experiments due to their seemingly limited interaction with the fiber that we assume arises from the asymmetry of the electron probability distribution and the reduction of the interaction through the spatial orientation of the atom with respect to the fiber. This work provides a critical step forward in the understanding of Rydberg–ONF interactions, which are essential for the continuation of experimental studies of Rydberg atoms at the surface of the dielectric, the development of Rydberg-based waveguide QED systems, and the generation of a 1D ordered array of Rydberg atoms for quantum simulations mediated by the nanofiber.

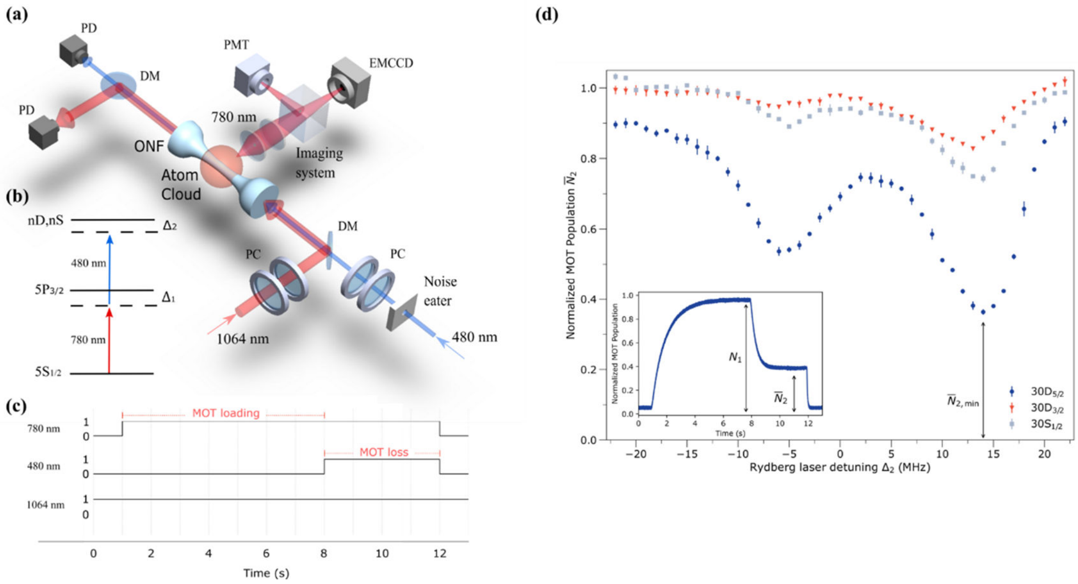

Figure 1: (a) Schematic of the experimental setup. [87]Rb atoms are trapped around the ONF in a MOT formed from six counterpropagating 780 nm beams. The excitation to the Rydberg state is driven by 480 nm light coupled into the ONF. The polarization of the 480 nm light is set using two λ/4 waveplates to maximize the excitation rate. The MOT population is measured using a PMT by collecting the fluorescence from the trapped atoms. ONF - optical nanofiber, PD - photodetector, DM - dichroic mirror, PC - polarization compensation, PMT - photomultiplier tube, EMCCD - electron multiplying CCD. (b) Energy level diagram for Rydberg excitation. The 780 nm cooling laser drives a transition between the $5S_{1/2}$and $5P_{3/2}$states, while the 480 nm laser excites atoms to the Rydberg state. The cooling and Rydberg lasers have detunings Δ_1 and Δ_2 from their respective transitions. (c) The timing sequence of the experiment. The MOT initially loads for 7 seconds. Once the 480 nm laser is turned on, the MOT starts losing atoms. After 4 seconds, both the 480 nm and 780 nm lasers are turned off and the experiment cycle recommences. The 1064 nm laser remains at a constant power throughout the experiments. (d) Normalized MOT population, (N_2) ̅, after Rydberg excitation as a function of the detuning, Δ_2, of the 480 nm laser for the $5P_{3/2}$ to $30S_{1/2}$ (gray squares), $30D_{3/2}$ (red triangles) and $30D_{5/2}$ (blue circles) transitions. The transitions to $ND_{5/2}$ states have higher excitation rates than the $NS_{1/2}$ and $ND_{3/2}$ states due to the larger dipole matrix element. Error bars represent the standard deviation of the 10 experimental measurements of (N_2) ̅and (N_2) ̅ $_{min}$ represents the minimum observed average population of the MOT after Rydberg excitation. The inset is a sample normalized MOT population curve when Δ_2 = 14 MHz for the $30D_{5/2}$, indicating how N_1 and N_2 are determined.

Publication:

Excitation of [87]Rb Rydberg atoms to nS and nD states (n<68) via an optical nanofiber

A Vylegzhanin, DJ Brown, A Raj, DF Kornovan, JL Everett, E Brion, J Robert and S Nic Chormaic

Optica Quant. **1**, 6 (2023)

3.2 Asymmetric split-ring plasmonic nanostructures for the optical sensing of Escherichia coli

Bacteria and other micro-organisms are responsible for many human diseases. Their rapid and accurate identification is crucial for effective treatment and the prevention of further infections. Here, we demonstrated a liquid bacterial Fano-Resonant Enhanced Raman Spectroscopy (FERS) platform that can be employed to produce valuable and repeatable bacterial spectral information in a liquid environment. Raman signatures of *Escherichia coli* were recorded at several locations on the metamaterial FERS surface, see Fig. 2. The proposed Fano-resonant biosensors can provide accurate detection of low-weight biological specimens at fairly low concentrations. The spectra were experimentally measured at 1×10^4 CFU/ml of *Escherichia coli* concentration for the mid-exponential phase while a higher concentration of 1×10^8 CFU/ml was used for the stationary phase. Compared to other analytical methods or SERS schemes, our approach opens a new set of opportunities for the development of better-performance FERS substrates that could enable the precise and rapid identification of bacteria, fungi or viruses in liquid.

We envision that this designed Fano-resonant nanostructures have strong potential to be employed in practical on-chip devices, enabling high specificity detection of biological substances in various environments.

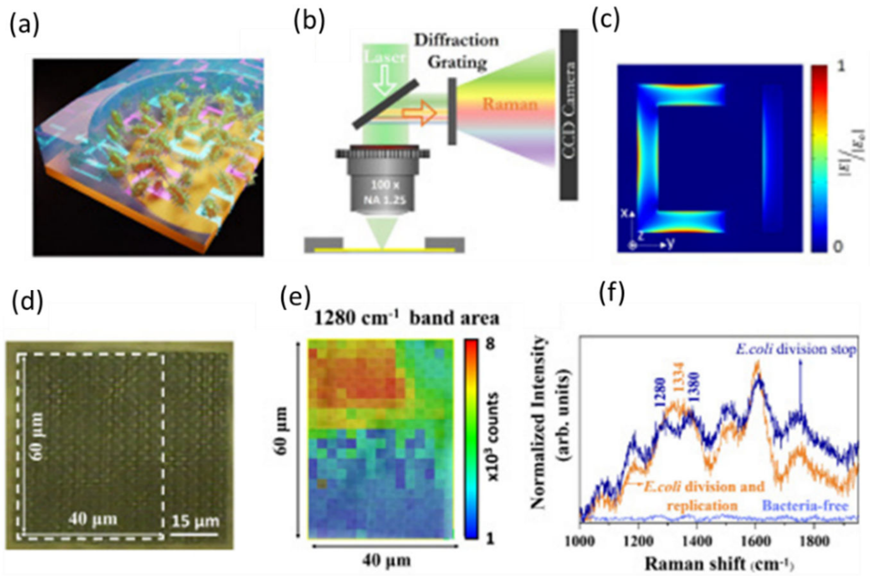

Figure 2: (a) An illustration image of *E.coli* on the metamaterial. (b) Schematic illustration of the experimental setup to collect the Raman spectrum of bacteria immobilized on the metamaterial. (c) The electromagnetic field enhancement of a single metamolecule at a simulated resonance of 6030 nm. (d) Microscope image of bacterial population on the metamaterial, where the distribution of *E.coli* is noted by the shaded areas. The white dashed rectangle shows the map area. (e) FERS mapping of bacterial population on the metamaterial in a liquid environment. The red and green regions show metabolically active bacteria whereas blue regions indicate that no bacteria were detected. (f) FERS spectra after baseline correction and normalization for the red, green, and blue positions noted in (e). The red positions in (e) provide a broad characteristic band at

1334 cm^{-1} that indicates CH deformation vibrations. The applied concentration of *E.coli* bacteria was 1×10^8 CFU/mL.

Publication:

Asymmetric split-ring plasmonic nanostructures for the optical sensing of Escherichia coli

DG Kotsifaki, RR Singh, S Nic Chormaic and VG Truong

Biomed. Opt. Express **14**, 4875 (2023)

3.3 Structural characterization of thin-walled microbubble cavities

Whispering gallery mode (WGM) microbubble cavities are a versatile optofluidic sensing platform owing to their hollow core geometry. To increase the light–matter interaction and, thereby, achieve higher sensitivity, thin-walled microbubbles are desirable. However, a lack of knowledge about the precise geometry of hollow microbubbles prevents us from having an accurate theoretical model to describe the WGMs and their response to external stimuli. In this work, we provide a complete characterization of the wall structure of a microbubble and propose a theoretical model for the WGMs in this thin-walled microcavity based on the optical waveguide approach. Structural characterization of the wavelength-scale wall is enabled by focused ion beam milling and scanning electron microscopy imaging, see Fig. 3. The proposed theoretical model is verified by finite element method simulations. Our approach can readily be extended to other low-dimensional micro-/nanophotonic structures.

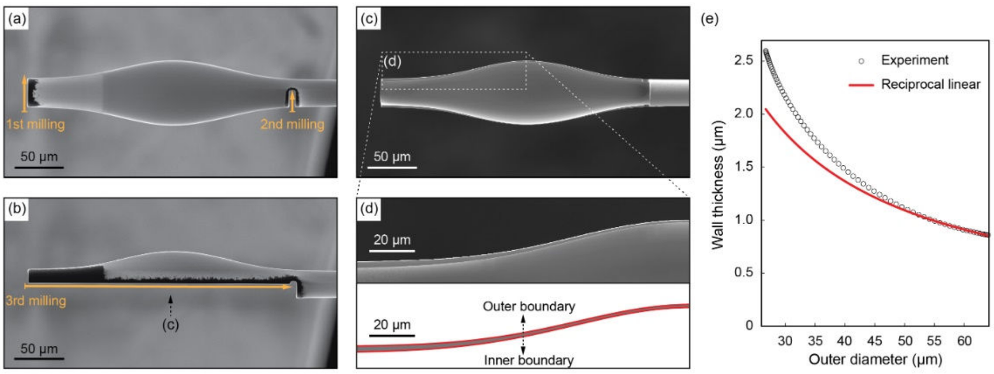

Figure 3: Structural characterization of a thin-walled microbubble by FIB milling and SEM imaging. (a) The microbubble's support stem on the left side was initially removed through FIB milling, while half of the support stem on the right side was cut, creating a gap. (b) A third FIB milling was conducted from the center of the left side towards the center of the gap on the right side, resulting in the removal of half of the microbubble. (c) After rotating the microbubble's left half, the wall structure of the microbubble is clearly visible under SEM imaging. (d) Due to the high SEM imaging resolution, the wall thickness variation along the cavity axis can be determined with accuracy down to the nanometer scale (upper panel). To describe such a wall structure, Gaussian profiles were used to fit the outer and inner boundaries of the microbubble (lower panel). (e) The dependence of the wall thickness t on the outer diameter d of the thin-walled

microbubble is shown. A reciprocal linear relation is satisfied near the center of the microbubble at larger outer diameters.

Publication:

Structural characterization of thin-walled microbubble cavities

MZ Jalaludeen, S Li, K Tian, T Sasaki and S Nic Chormaic

Photonics Res. **11**, A19 (2023)

3.4 Manipulation of polarization topology using a Fabry-Perot fiber cavity with a higher-order mode optical nanofibers

Optical nanofiber cavity research has mainly focused on the fundamental mode. Here, a Fabry–Pérot fiber cavity with an optical nanofiber supporting the higher-order modes (TE01, TM01, HE*o*21, and HE*e*21) was demonstrated. Using cavity spectroscopy, with mode imaging and analysis, we observed cavity resonances that exhibited complex, inhomogeneous states of polarization with topological features containing Stokes singularities such as C-points, Poincaré vortices, and L-lines, see Fig. 4. *In situ* tuning of the intracavity birefringence enabled the desired profile and polarization of the cavity mode to be obtained. We believe these findings open new research possibilities for cold atom manipulation and multimode cavity quantum electrodynamics using the evanescent fields of higher-order mode optical nanofibers.

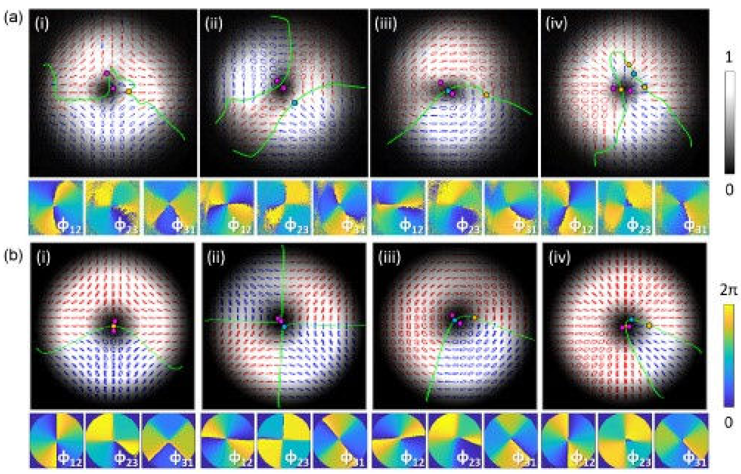

Figure 4: (a) Experimental beam profiles and associated phase diagrams. (b) Simulated results for (a).

Publication:

Manipulation of polarization topology using a Fabry-Pérot fiber cavity with a higher-order mode optical nanofibers

M Maeda, J Keloth and S Nic Chormaic

Photonics Res. **11**, 1029 (2023)

3.5 Enabling self-induced back-action trapping of gold nanoparticles in metamaterial plasmonic tweezers

The search for efficient nanoparticle trapping at low power levels has driven the evolution of optical tweezers from traditional free-space setups to plasmonic-based systems. Despite these advancements, trapping nanoparticles smaller than 10 nm remains challenging, even with plasmonic tweezers. Through the careful design and excitation of nanocavities, the phenomenon of self-induced back-action (SIBA) can enhance trap stiffness while reducing laser power requirements. We explored the SIBA effect in metamaterial tweezers and its association with the observed Fano resonance. We demonstrated the stable trapping of 20 nm gold particles with minimal excitation intensity. Simulations identified two distinct types of hotspots within the plasmonic array, each offering tunable trap stiffnesses. This unique feature has potential applications in sorting particles and biological molecules based on their properties. Figure 5 is a schematic representation of the experimental setup.

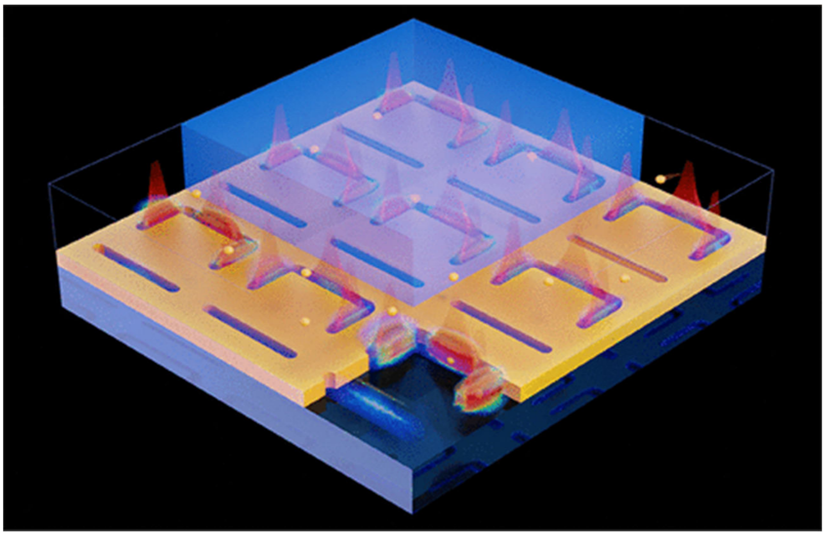

Figure 5: Schematic illustration of the metamaterial array consising of assymetric split resonator unit cells.

Publication:

Enabling self-induced back-action trapping of gold nanoparticles in metamaterial plasmonic tweezers

TD Bouloumis, DG Kotsifaki and S Nic Chormaic

Nano Lett. **23**, 4723 (2023)

4. Publications

4.1 Journals

1. Choi, K. R., Park, D. H., Chan, J. B., Lee, H. L., Kang, E. S. H., Nic Chormaic, S., Wu, J. W., D'Aleo, A. & Lee, Y. U. Photoluminescence lifetime engineering via organic resonant films with molecular aggregates.* *Nanophotonics* 13, 1033–1037, doi:https://doi.org/10.1515/nanoph-2023-0631 (2024).

2. Rodemund, T., Nic Chormaic, S. & Hentschel, M. Coupled deformed microdisk cavities featuring non-Hermitian properties.* *Applied Physics Letters* 124, doi:https://doi.org/10.1063/5.0180672 (2024).
3. Li, A., Ward, J., Tian, K., Yu, J., She, S., Hou, C., Guo, H., Nic Chormaic, S. & Wang, P. Evaporation characteristics of Er3+-doped silica fiber and its application in the preparation of whispering gallery mode lasers.* *Optics Express* 32, 3912-3921, doi:https://doi.org/10.1364/OE.509662 (2024).
4. Bathish, B., Douvidzon, M., Gad, R., Cheng, F., Carmon, T., Karlsson, K., Madugani, R. & Nic Chormaic, S. Plasma microcavities - featured in highlights of optics in 2023. *Optics & Photonics News* 34, 37 (2023).
5. Praveen Kamath, P., Sil, S., Truong, V. G. & Nic Chormaic, S. Particle trapping with optical nanofibers: a review [Invited]. *Biomedical Optics Express* 14, 6172-6189, doi: https://doi.org/10.1364/BOE.503146 (2023).
6. Praveen Kamath, P., Truong, V. G., Sil, S. & Nic Chormaic, S. Simulation of particle dynamics in the evanescent field of an ultrathin optical fiber. *Proc. of SPIE: Optical Trapping and Optical Micromanipulation XX* 12649, doi:https://doi.org/10.1117/12.2675705 (2023).
7. Vylegzhanin, A., Brown, D., Raj, A., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. Excitation of 87Rb Rydberg atoms to nS and nD states (n≤68) via an optical nanofiber. *Optical Quantum* 1, 6-13, doi:https://doi.org/10.1364/OPTICAQ.498414 (2023).
8. Sil, S., Praveen Kamath, P., Truong, V. G., Tkachenko, G. & Nic Chormaic, S. Optomechanical detection of the transverse spin of light using anisotropic probe particles in an evanescent field and optical tweezers. *Proc. of SPIE: Optical Manipulation and Structured Materials Conference* 12606, doi:https://doi.org/10.1117/12.3008337 (2023).
9. Cheng, Z., Zhang, Z., Wang, R., Wang, S., Li, X., Nic Chormaic, S., Jia, S. & Wang, P. Numerical modeling of dual-wavelength pumped heavily-Ho3+-doped fluoroindate fiber lasers with efficient output at 3.92 µm. *Journal of Lightwave Technology* 41, 7021-7028, doi: https://doi.org/10.1109/JLT.2023.3295126 (2023).
10. Kotsifaki, D., Singh, R. R., Nic Chormaic, S. & Truong, V. G. Asymmetric split-ring plasmonic nanostructures for the optical sensing of Escherichia coli. *Biomedical Optics Express* 14, 4875-4887, doi:https://doi.org/10.1364/BOE.497820 (2023).
11. Kotsifaki, D., Bouloumis, T., Truong, V. G. & Nic Chormaic, S. Manipulation, trapping, and biosensing using metamaterial devices. *Biophotonics Congress: Optics in the Life Sciences 2023 (OMA, NTM, BODA, OMP, BRAIN)* Technical Digest Series (Optica Publishing Group, 2023), paper ATu2D.2, doi:https://doi.org/10.1364/OMA.2023.ATu2D.2 (2023).
12. Stourm, E., Lepers, M., Robert, J., Nic Chormaic, S., Molmer, K. & Brion, E. Rydberg atoms in the vicinity of an optical nanofiber. *Biophotonics Congress: Optics in the Life Sciences 2023 (OMA, NTM, BODA, OMP, BRAIN)* Technical Digest Series (Optica Publishing Group, 2023), doi:https://doi.org/10.1364/OMA.2023.AW1D.1 (2023).
13. Nic Chormaic, S., Tkachenko, G., Esporlas, C. L., Sanskriti, I. & Truong, V. G. Manipulation of Janus particles using optical nanofibers. *Biophotonics Congress: Optics in the Life Sciences 2023 (OMA, NTM, BODA, OMP, BRAIN)* Technical Digest Series (Optica Publishing Group, 2023), doi:https://doi.org/10.1364/OMA.2023.ATh1D.2 (2023).

14. Jalaludeen, M. Z., Li, S., Tian, K., Sasaki, T. & Nic Chormaic, S. Structural characterization of thin-walled microbubble cavities. *Photonics Research* 11, A190A125, doi: https://doi.org/10.1364/PRJ.495072 (2023).
15. Baheej, B., Raanan, G., Cheng, F., Karlsson, K., Madugani, R., Douvidzon, M., Nic Chormaic, S. & Carmon, T. Absorption-induced transmission in plasma microphotonics. *Nature Communications* 14, doi:https://doi.org/10.1038/s41467-023-40205-0 (2023).
16. Maeda, M., Keloth, J. & Nic Chormaic, S. Manipulation of polarization topology using a Fabry–Pérot fiber cavity with a higher-order mode optical nanofiber. *Photonics Research* 11, 1029-1037, doi:https://doi.org/10.1364/PRJ.486373 (2023).
17. Bouloumis, T., Kotsifaki, D. & Nic Chormaic, S. Enabling self-Induced back-action trapping of gold nanoparticles in metamaterial plasmonic tweezers. *Nano Lett.* 23, 4723–4731, doi:https://doi.org/10.1021/acs.nanolett.2c04492 (2023).
18. Vople, G., Tkachenko, G., Truong, V. G. & Nic Chormaic, S. Roadmap for optical tweezers: 4. Optical trapping and manipulation mediated by optical nanofibres. *Journal of Physics: Photonics* 5, doi: https://doi.org/10.1088/2515-7647/acb57b (2023).

**main work done outside OIST*

4.2 PhD Thesis

- Bouloumis, TD. Metamaterial plasmonic tweezers for enhanced nanoparticle trapping.
OIST Graduate University, Japan (2023)
- Maeda, M. Design, fabrication, and characterization of optical nanofibre cavities
OIST Graduate University, Japan (2024)

4.3 Books and other one-time publications

Nothing to report

4.4 Oral and Poster Presentations

4.4.1 Invited Talks

1. Nic Chormaic, S. *Optical nanofiber based hybrid quantum systems:* SPIE Photonics West, San Francisco, USA, 01 February (2024).
2. Nic Chormaic, S. *Optical nanofibers and nanofiber based particle trapping:* JSAP Photonics Division Workshop, Naha, Japan, 02 November (2023).
3. Brown, D. *Excitation of Rydberg atoms next to an optical nanofiber for waveguide QED experiments:* Okinawa School in Physics: Coherent Quantum Dynamics, Okinawa, Japan, 5 October (2023).
4. Truong, V. G., Praveen Kamath, P., Sil, S., Tkachenko, G. & Nic Chormaic, S. *Selective trapping, rotation and propulsion of isotropic dielectric and composite Janus microparticles in the evanescent field of optical nanofibres:* JSAP Autumn meeting, Kumamoto, Japan, 19 September (2023).

5. Kotsifaki, D., Ripken, C., Truong, V. G. & Nic Chormaic, S. *Using near-field optics to manipulate and characterise marine particles:* CLEO, San Jose, USA, 11 May (2023).
6. Nic Chormaic, S. *Optical nanofibres and nanofibre based cavities:* wQED2023, Erice, Italy, 10 May (2023).
7. Nic Chormaic, S. *Optical manipulation of Janus particles using optical nanofibers(virtual session)*: MRS Spring Meeting 2023, San Francisco, USA, 26 April (2023).

4.4.2 Contributed Talks

1. Nic Chormaic, S. *Metamaterial plasmonic arrays for particle trapping and detection*: Nanolight 2024, Benasque, Spain, 01 March (2024).
2. Brown, D. *Excitation of Rydberg atoms next to an optical nanofiber for waveguide QED experiments:* ONNA2023, Okinawa, Japan, 15 December (2023).
3. Vylegzhanin, A. *Nanofiber-based state-insensitive fictitious magnetic field trap for ground and Rydberg state ^{87}Rb atom:* ONNA2023, Okinawa, Japan, 15 December (2023).
4. Maeda, M. *Fabry-Pérot fiber cavity with a higher-order mode optical nanofiber: manipulation of polarization topology:* ONNA2023, Okinawa, Japan, 15 December (2023).
5. Jalaludeen, M. Z., Begumya, S., Tian, K., Li, S. & Nic Chormaic, S. *Interfacing single NV–centers in diamonds with low dimensional optical cavities for all-fiber quantum networks:* ONNA2023, Okinawa, Japan, 15 December (2023).
6. Praveen Kamath, P., Truong, V. G., Sil, S. & Nic Chormaic, S. *Simulation of particle dynamics in the evanescent field of an ultrathin optical fiber*: SPIE Optics+Photonics 2023, San Diego, USA, 23 August (2023).
7. Vylegzhanin, A., Brown, D., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. *Rydberg excitation and Casimir-Polder interaction of 87-Rb atoms mediated by an optical nanofiber (Hot topic talk):* 792 WE Heraeus Seminar on Applications of Ultracold Rydberg Gases, Bad Honnef, Germany, 24 July (2023).
8. Nic Chormaic, S., Tkachenko, G., Esporas, C. L., Sanskriti, I. & Truong, V. G. *Manipulation of Janus particles using optical nanofibers:* Optica Biophotonics Congress: Optics in the Life Sciences - Optical Manipulation and Its Applications, Vancouver, Canada, 27 April (2023).
9. Stourm, E., Lepers, M., Robert, J., Nic Chormaic, S., Moelmer, K. & Brion, E. *Rydberg atoms in the vicinity of an optical nanofiber:* Optica Biophotonics Congress: Optics in the Life Sciences - Optical Manipulation and Its Applications, Vancouver, Canada, 26 April (2023).
10. Kotsifaki, D., Bouloumis, T., Truong, V. G. & Nic Chormaic, S. *Manipulation, trapping, and biosensing using metamaterial devices:* Optica Biophotonics Congress: Optics in the Life Sciences - Optical Manipulation and Its Applications, Vancouver, Canada, 25 April (2023).
11. Madugani, R., Cheng, Z., Wang, P. & Nic Chormaic, S. *Spin-orbit coupling of light in the whispering gallery mode microcavities:* ICNN 2023, Yokohama, Japan, 21 April (2023).
12. Praveen Kamath, P., Truong, V. G., Sil, S. & Nic Chormaic, S. *Simulation of Janus particle in the evanescent field of a nanofiber:* OMC 2023, Yokohama, Japan, 19 April (2023).
13. Truong, V. G. *Metamaterial plasmonic tweezers: Particle and molecule trapping, and its applications in ultrasensitive Escherichia coli Raman spectroscopy detection:* OMC 2023, Yokohama, Japan, 19 April (2023).

14. Sil, S., Praveen Kamath, P., Truong, V. G., Tkachenko, G. & Nic Chormaic, S. *Optomechanical detection of the transverse spin of light using anisotropic probe particles in an evanescent field and optical tweezers:* OMC 2023, Yokohama, Japan, 19 April (2023).

4.4.3 Posters

1. Rodemund, T., Li, S., Nic Chormaic, S. & Mentschel, M. *Phase-space representations of three-dimensional optical microcavities:* DPG Spring Meeting, Berlin, Germany, 20 March (2024).
2. Hassan, F., Truong, V. G., Nic Chormaic, S. & Luscombe, C. *Bioinspired photonic materials from cellulose and functionalization by photochromic molecular switch:* OIST-Kyudai Joint Symposium Series 1: Bio-Inspired Wonders and Energy Innovations, Okinawa, Japan, 29 February (2024).
3. Maeda, M. *Optical nanofiber microcavity for non-atomic strong coupling quantum system:* QIT49, Okinawa, Japan, 17-19 December (2023).
4. Praveen Kamath, P., Truong, V. G., Sil, S. & Nic Chormaic, S. *Janus particle trapping in the evanescent field of an optical nanofiber:* ONNA2023, Okinawa, Japan, 15 December (2023).
5. Begumya, S., Jalaludeen, M. Z., Tian, K., Li, S. & Nic Chormaic, S. *Creation and characterization of NV centers in diamond:* ONNA2023, Okinawa, Japan, 15-16 December 2023.
6. Sil, S., Praveen Kamath, P., Truong, V. G. & Nic Chormaic, S. *Demonstration of transverse spin of light by probing anisotropic particle in evanescent field:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
7. Shahrabifarahani, Z., Maeda, M., Everett, J., Li, W. & Nic Chormaic, S. *Structured optical nanofibers for atom trapping:* ONNA2023, Okinawa, Japan, 15 December (2023).
8. Jose, A., Madugani, R., Singh, R. & Nic Chormaic, S. *Detection of magnetotactic bacteria using a microbubble whispering gallery mode resonator:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
9. Maeda, M. *Optical nanofiber microcavity for non-atomic strong coupling quantum system:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
10. Madugani, R. *Microbubble whispering gallery mode resonators and applications:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
11. Li, W., Du, J., Wilson, C. M., Bajcsy, M. & Nic Chormaic, S. *Tailoring light-matter interaction using optical waveguide:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
12. Perez-Lobato, G. A., Li, W. & Nic Chormaic, S. *Thin film tailored optical nanofiber for strong light-matter interaction:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
13. Raj, A., Vylegzhanin, A., Brown, D., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. *Excitation of Rydberg atoms at the interface of an Optical nanofiber:* ONNA2023, Okinawa, Japan, 15-16 December (2023).
14. Hassan, F., Truong, V. G., Nic Chormaic, S. & Luscombe, C. *Light-Driven Molecular Switching Based on Liquid Crystalline Cellulosic Polymers:* 10th International Symposium On Photochromism, ISOP 2023, Nara, Japan, 07 November (2023).
15. Begumya, S., Jalaludeen, M. Z., Tian, K., Li, S. & Nic Chormaic, S. *Femtosecond pulse laser writing of nitrogen vacancy defects in diamond:* JSAP Photonics Division Workshop, Naha, Japan, 02 November (2023).

16. Praveen Kamath, P., Truong, V. G., Sil, S. & Nic Chormaic, S. *Simulation of Janus particle dynamics in the evanescent field of an optical nanofiber:* JSAP Photonics Division Workshop, Naha, Japan, 02 November (2023).
17. Jose, A., Madugani, R., Singh, R. & Nic Chormaic, S. *Detection of magnetotactic bacteria using a microbubble whispering gallery mode resonator:* JSAP Photonics Division Workshop, Naha, Japan, 02 November (2023).
18. Jalaludeen, M. Z., Begumya, S., Tian, K., Li, S. & Nic Chormaic, S. *Towards quantum communication with single NV centers and low dimensional optical microcavities:* JSAP Photonics Division Workshop, Naha, Japan, 02 November (2023).
19. Raj, A., Vylegzhanin, A., Brown, D., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. *Excitation of Rydberg atoms at the interface of an Optical nanofiber:* JSAP Photonics Division Workshop, Naha, Japan, 02 November (2023).
20. Hassan, F., Truong, V. G., Nic Chormaic, S. & Luscombe, C. *Light-Driven Cellulose Nanocrystals Enabled by Photochromic Molecular Switch:* 2023 Japan-US Symposia on Polymer Chemistry: Meeting the Challenges of a Sustainable Society with Macromolecules, OIST, Okinawa, Japan, 30 October (2023).
21. Li, W., Du, J., Wilson, C. M., Bajcsy, M. & Nic Chormaic, S. *Tailoring light-matter interaction using optical waveguide* 1st International Workshop on Quantum Information Engineering (QIE2023), Okinawa, Japan, 11 October (2023).
22. Li, W., Du, J., Wilson, C. M., Bajcsy, M. & Nic Chormaic, S. *Tailoring light-matter interaction using optical waveguide: Okinawa School in Physics:* Coherent Quantum Dynamics, Okinawa, Japan, 29 September (2023).
23. Raj, A., Vylegzhanin, A., Brown, D., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. *Evanescent field mediated Rydberg interactions via an Optical nanofiber:* Okinawa School in Physics: Coherent Quantum Dynamics, Okinawa, Japan, 29 September (2023).
24. Jalaludeen, M. Z., Begumya, S., Tian, K., Li, S. & Nic Chormaic, S. *Interfacing single photon sources with low dimensional optical microresonators:* Okinawa School in Physics: Coherent Quantum Dynamics, Okinawa, Japan, 29 September (2023).
25. Li, S., Jalaludeen, M. Z., Begumya, S., Tian, K. & Nic Chormaic, S. *Characterization and modeling of hollow bottle microresonators:* Okinawa School in Physics: Coherent Quantum Dynamics, Okinawa, Japan, 29 September (2023).
26. Rodemund, T., Nic Chormaic, S., Sinzinger, S. & Hentschel, M. *Mesoscopic optics in coupled microcavities*: EOSAM 2023, Dijon, France, 13 September (2023).
27. Choi, K. R., Li, S., Ozerov, I., Bedu, F., Park, D. H., Joo, B. C., Wu, J. W., Nic Chormaic, S. & Lee, Y. U. *Fabrication of plasmonic metasurfaces for fluorescence nanoscopy:* Journees Plenieres du GDR Plasmonique Actives, Marseille, France, 11 July (2023).
28. Raj, A., Vylegzhanin, A., Brown, D., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. *Excitation of ^{87}Rb Rydberg atoms to nS and nD states ($n\leq68$) via an optical nanofiber:* 2023 Atomic Physics, Gordon Research Conference, Rhode Island, USA, 13 June (2023).
29. Raj, A., Vylegzhanin, A., Brown, D., Kornovan, D. F., Everett, J., Brion, E., Robert, J. & Nic Chormaic, S. *Excitation of ^{87}Rb Rydberg atoms to nS and nD states ($n\leq68$) via an optical nanofiber:* 2023 Atomic Physics, Gordon Research Seminar, Rhode Island, USA, 11 June (2023).

30. Jalaludeen, M. Z., Begumya, S., Du, Y., Li, S. & Nic Chormaic, S. *Cavity quantum electrodynamics with single NV-centers and hollow whispering gallery resonators:* ICNN 2023, Yokohama, Japan, 20 April (2023).

4.5 Seminar (outside OIST)

1. Vylegzhanin, A. *Excitation of Rb-87 Rydberg atoms next to an optical nanofiber,* ICFO, Barcelona, Spain, 27 February (2024).
2. Nic Chormaic, S. *Optical nanofibres and cold rubidium atoms (QuCoLiMa Seminar),* Johannes Gutenberg University Mainz, Germany, 07 November (2023).
3. Brown, D. *Excitation of Rydberg atoms next to an optical nanofiber for waveguide QED experiments,* University of Auckland Department of Physics Colloquium, Auckland, New Zealand, 25 October (2023).
4. Nic Chormaic, S. *Optical nanofibres and cold Rb atoms,* Institute of Physics, Rostock University, Germany, 31 August (2023).
5. Nic Chormaic, S. *Trapping micro and nanoparticles using near-field optics,* Dept. of Physics Seminar, Technische Universitaet Chemnitz, Germany, 21 June (2023).
6. Nic Chormaic, S. *Trapping particles using near-field optics,* Dept. of Physics Colloquium, Toronto Metropolitan University, Canada, 12 June (2023).
7. Madugani, R. *Optical microcavities, fabrication and applications,* Joint Seminar of the Theory Groups, TU Chemnitz, University of Technology, Germany, 24 May (2023).
8. Brown, D. *Rydberg excitations next to optical nanofibers,* University of Bonn Weekly Seminar, Germany, 19 May (2023).

4.6 Lecture (outside OIST)

1. Nic Chormaic, S. *From cold atoms to microbeads - manipulation using ultrathin fibres,* Optica Student Chapter Lecture IISER Pune, India, online, 13 February (2024).
2. Nic Chormaic, S. *Lectures on Quantum Sensing,* International Summer School in Quantum Technologies, University of Birmingham, United Kingdom, 01-10 August (2023).

5. Intellectual Property Rights and Other Specific Achievements

International Patent Filed PCT/IL2024/050140 "Laser based on a dielectric resonator with gas or plasma at population inversion". T. Carmon, R. Gad and S. Nic Chormaic.

6. Meetings and Events

6.1 Seminar

Title: Nanoaperture Optical Tweezers: From single proteins to quantum emitters
Date: March 21, 2024

Venue: C210
Speaker: Prof. Reuven Gordon (University of Victoria, Canada)

Title: Analytical Methods for Near-Field Optics (Lecture)
Date: March 19, 2024
Venue: L4E01
Speaker: Prof. Reuven Gordon (University of Victoria, Canada)

Title: Atom-interferometry based Quantum gravimeter for field applications
Date: March 19, 2024
Venue: on Zoom
Speaker: Dr. Ravi Kumar (Atomionics Pte, Ltd, Singapore)

Title: Ultracold atoms carrying orbital angular momentum in lattices of rings
Date: March 18, 2024
Venue: on Zoom
Speaker: Dr. Verónica Ahufinger (Universitat Autònoma de Barcelona, Spain)

Title: Dipolar quantum gases: From rotons to supersolids
Date: March 11, 2024
Venue: on Zoom
Speaker: Dr. Manfred Mark (Institut für Experimentalphysik, Universität Innsbruck, Austria)

Title: Guiding Light to Non-Classicality
Date: February 21, 2024
Venue: on Zoom
Speaker: Dr. Philipp Schneeweiss (Humboldt University, Germany)

Title: Ultrafast Rydberg experiments with ultracold atoms
Date: February 21, 2024
Venue: C209, OIST
Speaker: Dr Sylvain de Léséleuc (Institute for Molecular Science, Japan)

Title: Quantum computing with optical tweezer trapped arrays of neutral atoms
Date: February 14, 2024
Venue: on Zoom
Speaker: Dr. Ratnesh Kumar Gupta (5th Quantum Institute, University of Stuttgart, Germany)

Title: Loading of cavities in vacuum using femtosecond laser melt-out technique
Date: February 5, 2024
Venue: on Zoom
Speaker: Dr. Nafia Rahaman (Quantum Nanophysics Group, University of Vienna, Austria)

Title: Photon-photon interactions in waveguide quantum electrodynamics
Date: September 11, 2023
Venue: on Zoom
Speaker: Prof. Alexander Poddubny (Weizmann Institute of Science, Israel)

Title: Waveguide QED with Rydberg superatoms
Date: April 17, 2023
Venue: on Zoom
Speaker: Nina Stiesdal (Institute of Applied Physics, University of Bonn, Germany)

6.2 CQD2023: Okinawa School in Physics: Coherent Quantum Dynamics

- Date: September 26 – October 5, 2023
- Venue: Seaside House, Okinawa
- Organisers: Thomas Busch (OIST), Síle Nic Chormaic (OIST), Kae Nemoto (OIST)

- Lecturers:
  - Mikhail (Misha) Baranov (IQOQI Innsbruck, Austria)
  - David Elkouss (OIST, Japan)
  - John Goold (Trinity College Dublin, Ireland)
  - Dieter Meschede (University of Bonn, Germany)
  - Giulia Semeghini (Harvard University, USA)
  - Birgit Stiller (Max Planck Institute for the Science of Light, Germany)
  - Shigeki Takeuchi (Kyoto University, Japan)
  - Arghavan Safavi (University of Amsterdam, Netherland)
- Colloquium Speakers:
  - Serge Haroche (Collège de France and Laboratoire Kastler Brossel, Paris)
  - Hideo Kosaka (Yokohama National University, Japan)
  - Takashi Yamamoto (Osaka University, Japan)

6.3 ONNA2023: Optical Nanofibre Applications: From Quantum to Bio Technologies

- Date: December 15-16, 2023
- Venue: Lab 5, OIST, Okinawa
- Organisers: Síle Nic Chormaic (OIST)

- Speakers:
  - Mark Sadgrove (Tokyo University of Science, Japan)
  - Christophe Pin (Hokkaido University, Japan)
  - Kali Prasanna Nayak (University of Electro-Communications, Japan)
  - Rui Sun (Tohoku University, Japan)
  - Yining Xuan (Tohoku University, Japan)
  - Bhavya Puthanveettil (University of Electro-Communications, Japan)
  - Haruto Kon (University of Electro-Communications, Japan)

6.4 Research Visit

- Dr Sylvain de Leseleuc, Institute for Molecular Science, Okazaki, Japan, 21-24 February 2024
- Prof Kali Prasanna Nayak, University of Electro-Communications, Japan, 15-16 December 2023
- Bhavya Puthanveettil, University of Electro-Communications, Japan, 15-16 December 2023
- Haruto Kon, University of Electro-Communications, Japan, 15-16 December 2023
- Prof Christophe Pin, Hokkaido University, Japan, 15-16 December 2023
- Prof Mark Sadgrove, Tokyo University of Science, Japan, 15-16 December 2023
- Kenyuu Mori, Tokyo University of Science, Japan, 15-16 December 2023
- Yamato Iida, Tokyo University of Science, Japan, 15-16 December 2023
- Yining Xuan, Tohoku University, Japan, 15-16 December 2023
- Rui Sun, Tohoku University, Japan, 15-16 December 2023
- Dr Jana Pilatova, Charles University, Czech Republic, 04 April 2023
- Matthew Deonarine, Toronto Metropolitan University, Canada, 12 March - 08 April 2023
- Prof Alexandre (Sasha) Douplik, Toronto Metropolitan University, Canada, 03 March - 26 April 2023

7. Other

- Two PhD students graduated, Dr Maki Maeda and Dr Theodoros Bouloumis
- Prof. Nic Chormaic continued to be funded to run the Chimu-Gukuru research internships for students from Ukraine and Russia
- Drs Ramgopal Madugani, Souvik Sil, Viet Giang Truong and Prof. Nic Chormaic won JSPS KAKENHI grants

Prof. Nic Chormaic assumed the following roles:

- Editorial Board Member for SPIE Advanced Photonics
- Advisory Editorial Board Member for SPIE Advanced Photonics Nexus
- Editorial Advisory Board Member for AVS Quantum Science (AQS)
- Committee Member for SPIE Structured Light Conference: OMC Japan
- Committee Member for ICNN 2022 Conference Japan
- Committee Member for EOSAM 2023 - Quantum Optics Meeting, France
- Commitee Member Advanced Photonics Conference San Diego USA
- General Chair for Optical Manipulation & Applications Conference at Optics in the Life Sciences - Biophotonics Congress, Canada
- SPIE EDI Committee Member
- SPIE Membership and Communities Committee Member
- Discussion Leader at Gordon Research Conference on Microlasers, Mount Snow, USA
- External faculty evaluator for TCD Ireland and Unviersity of Munster Germany
- Expert evaluation Alexander von Humboldt Foundation Germany
- Visiting Fellowship, TU Chemnitz, Germany
- IEEE Photonics Society Awards Section Commitee for Laser Instrumentation Award 2023
- Hong Kong Research Council Reviewer

- External MSc Examiner, Toronto Metropolitan University, Canada
- External PhD Examiner, University of Hanover, Germany