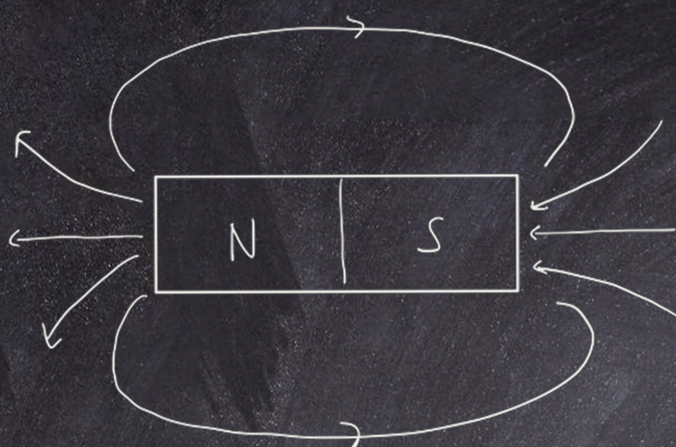
HERIOT WATT UNIVERSITY

Physics Department Newsletter

Volume 2, Issue 03

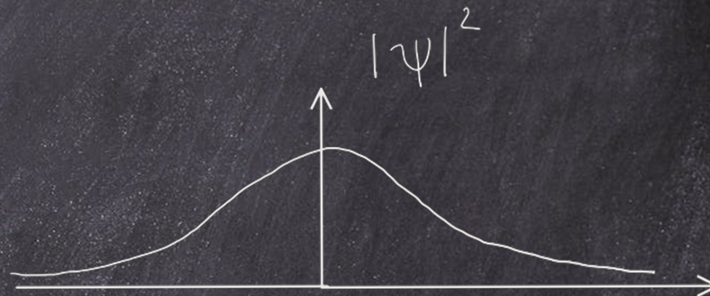


$$\nabla \cdot \vec{E} = \frac{1}{\varepsilon_0} \rho$$

$$\nabla \cdot \vec{B} = 0$$

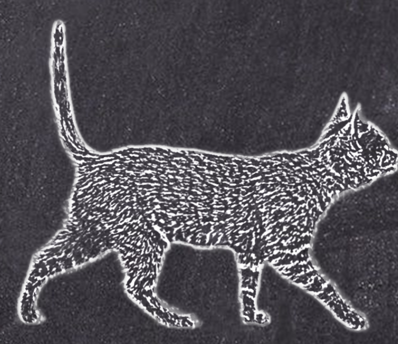
$$\nabla \times \vec{E} = -\frac{\partial}{\partial t} \vec{B}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial}{\partial t} \vec{E}$$



$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) = \frac{\partial L}{\partial x}$$

$$m\ddot{x} = -kx$$



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Physics Newsletter

Vol. 3, Issue 01 December 2022

We’re Getting the Band Back Together!

Sabrina Henry, Physics Society President

This year we are restarting the physics society! After a long two years of not being able to meet in person, we hope it will help students from all years rediscover a sense of community in physics. It is open to undergrads and postgrads (and not just restricted to those who study physics).

We hope to carry forward the parts of the society that people enjoyed in the past, such as colloquiums, games nights and maybe even some lecturer vs student events! As well as coming up with creative new socials.

This year also sees the return of the Watts Up balloon project that started in 2019 with the aim of sending a weather balloon into the atmosphere and live streaming data back to campus.

So far this semester we have had great success at the Freshers fayre where we had a stall and were able to display one of the Watts Up weather balloons. We also had our first social in week 1 and colloquium with Bill MacPherson in week 2. Both were very well attended so thanks to everyone who came along! We plan to have a colloquium every second Wednesday in the physics study room at 3 pm.

The best way to stay up to date with society is to join through the student union website – it's free and will ensure you are sent emails keeping you up to date on our activities.

For more information email physoc@hw.ac.uk and if you are interested in being involved in the Watts Up project get in touch with Sven (ss465@hw.ac.uk) or Prab (ps115@hw.ac.uk).

Automating a Photon Detector for Remote Measurements

Adam Patton, 4th year Physics Student

This summer I had the opportunity to join Dr Ross Donaldson’s research group to undertake the task of trying to automate a photon detector for remote measurements, as part of a larger aim to monitor and reduce background light pollution for quantum communications.

My task was to automate a Moku:Go data logger, using Matlab to open, run the device for a specified time, and then finally close the device. My initial plan was to write multiple functions that

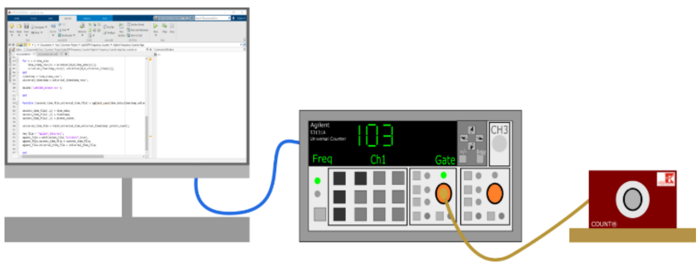


Fig 1. Diagrammatic set-up used to record data using the photon detector. To record a dark count, a blackout sheet was also used to cover the detector.

could connect and configure the Moku:Go device to a specific set-up, log the data for an input time and convert the output file to a csv for use in Matlab. Once this had been done I could then determine a count rate of the data by setting a threshold voltage to cancel out noise as counting as a photon detection, and converting all values above this threshold to a logical “1” and everything below as a logical “0”. With this I could then take a second identical data set and shift all data values one cell to the right. Now I could finally use an XOR function on the shifted data and the original to obtain a logical “1” at time values that a photon had been detected, and half the sum of all the “1” values divided by the total time taken would give me a count rate in counts per second. Unfortunately, due to eventual file conversion and app issues, the Moku:Go device could not be fully automated, so this led to a new route to automation.

This new route was a Keysight Agilent frequency counter as seen in the figures 1 & 2 – which from the get go seemed like a much more viable option. Labview code was used to automate the Agilent device, which in turn could be packaged as an application to be used by Matlab through the use of system commands. This meant that all LabVIEW code was essentially hidden – which makes it much easier for the experimentalist to use – as there is no jumping back and forth between coding languages.

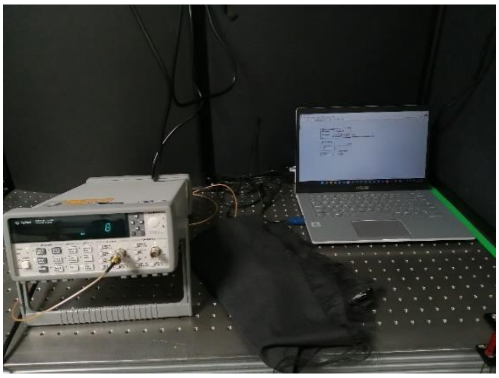


Fig 2. The actual set-up recording data in the lab. As you can see, the count rate is displayed on the frequency counter whilst the blackout sheet is covering the photon detector to record a dark count rate.

Luckily, there was a driver available to download for LabVIEW that contained packaged functions, to set up the device and run it. With a few extra inputs I could run a function for a specified time and save the needed outputs to a csv file. With the code ready in LabVIEW and packaged as an executable, I could then write two functions in Matlab, which would start the device and record data for a certain time using the now created LabVIEW application, and the other would read in the input file with the data, assign it correspondingly and even create timestamps, which it could then output for further use or plotting.

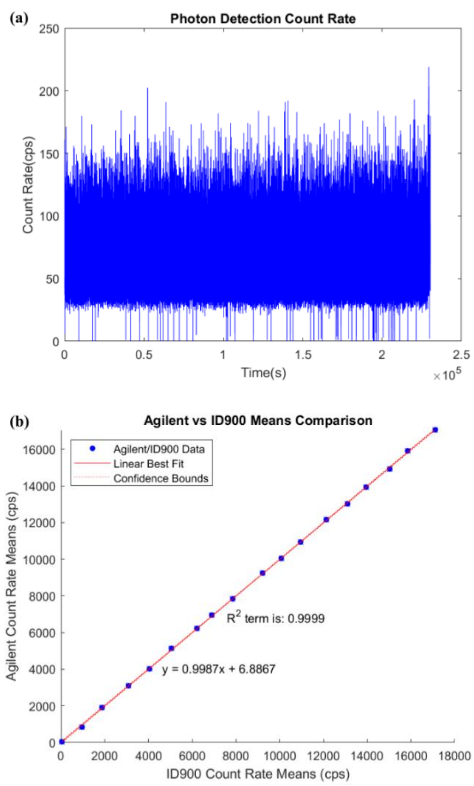


Fig 3 **(a).** *The resulting output count rate over 64 hours of the Agilent using the Matlab code.* **(b)** *Linear regression comparison plot of Agilent data vs ID900 data from a dark count rate to ~18kc/s in 1kc/s steps as best as the lighting conditions could be restricted.*

The Agilent device is now successfully automated through Matlab, with only a run time input required. To verify that the readings taken were correct, an IDQ ID900 Time Controller was used to act as the "true" data set of the photon counter, and from this and by changing lighting conditions to increase or decrease photon detection, a linear regression plot could be obtained through Matlab to compare photon detection count rates between the two devices. From this plot, an R^2 term could also be obtained, which tells us how well the data matches to the linear best fit, where a value of 0.9997 was obtained, indicating that the two devices provide near identical results compared to the linear model, which also can be used to correct any offset that may have to be applied to the Agilent.

The next steps for this device are to correct any defects in measurement reading from the linear regression plot, and then to integrate this system into a larger one that will take real life data, as shown in Figure 4 below. To replicate the actual light data, a photon detector has been used here, but in the bigger

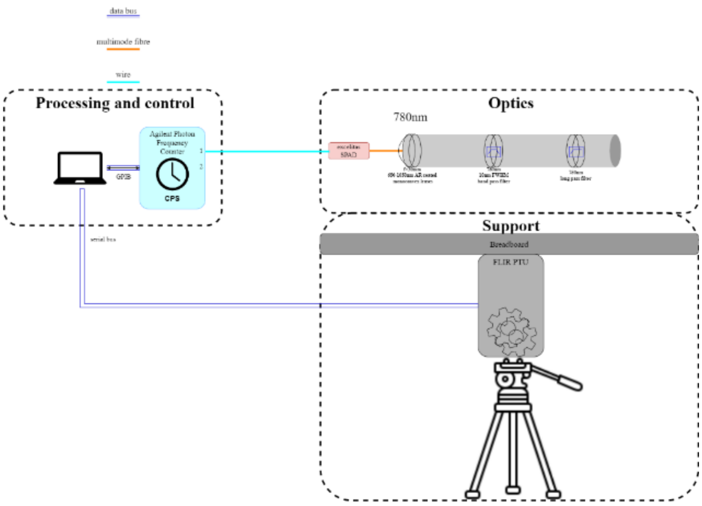


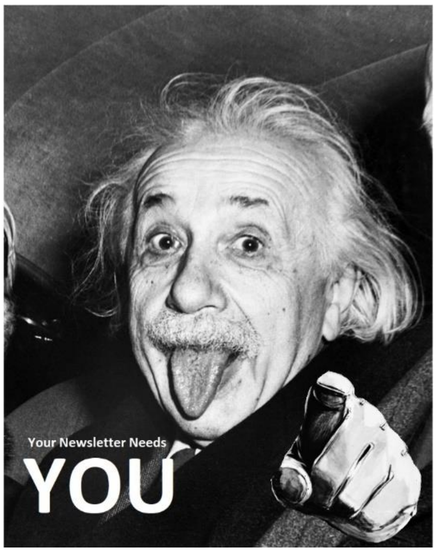
Fig 4. The complete set-up with the Agilent device and laptop controller as part of the full system consisting of a photon detector placed on a sweeping controlled platform.

experiment the light data will be collected from pointing photon detectors into the sky, which will sweep about the sky on a controlled platform.

Physics Newsletter - Join The Team!

Newsletter team – Dr. R. Donaldson, S. Keenan, M. Damyanov.

The events of 2020 put a spanner in the works of everyday university life; no face-to-face teaching, no seminars, and no social events. Our Editor, Sean Keenan, set up the student-led Physics Department Newsletter in September 2020 to share stories, research articles, and brainteasers. The aim was to build community within the department without our usual ways.



Since its inception, we have released 7 newsletters (this being our 8th). We have shared some great pieces over the past couple of years; one of our favourite pieces involves measuring a radioactive cat's half-life post-surgery.

As with all academic and social societies, we are looking for fresh new faces/volunteers to join our team to help us to continue to produce the newsletter. We are looking for volunteers to help edit, do creative design/photoshop, or want to contribute material (articles, opinion pieces, or puzzles).

For more information email physicsnews@hw.ac.uk or one of our editorial team.

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Associate Academic Editor:

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Two-Photon Absorption Detector for High-Speed Optical Sampling

Sven Stengel, 4th Year Physics student

Doing a summer project in a research group is a great experience which grants you many insights into how actual research at an academic level is done. This includes things like setting and discussing goals with your supervisor, learning to operate loads of scientific equipment, and working much more independently compared to the undergraduate labs. Therefore, it will give you a good basis for any upcoming experimental and computer labs as well as the Bachelor or Master project. Besides that, you get the opportunity to get insights into the everyday work of PhD students and your supervisor.

The summer project I worked on was in Dr. Maria Ana Cataluna's Ultrafast Photonics Group (UP Group) and was focused on finding a suitable two-photon absorption (TPA) detector for further use in their high-speed optical sampling setup. TPA is a third order non-linear optical effect, where two photons are absorbed at once. This can be explained using a virtual state which has half of the bandgap energy. If then two photons pass through the material at the same instant and location, they can bridge the band gap and TPA occurs. The key difference to single-photon absorption (SPA) is that TPA is highly dependent on intensity. Therefore, it is favourable to work with short and intense laser pulses or powerful continuous lasers that are focused to very small spot sizes. In our setup a pulsed laser was used in combination with a microscope objective to achieve the significant intensity threshold to observe TPA. Most materials will show SPA at lower powers and then transition to TPA, an example of one experimental result can be seen in figure 1.

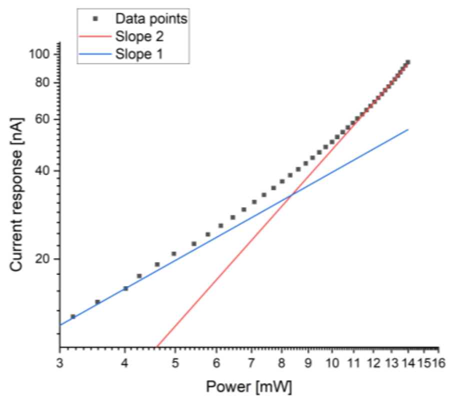

Fig 1. The current response of a silicon photodiode as the incident power is increased. The TPA data is displayed as a log-log plot, where the blue line is of slope 1, indicating SPA, and the red line has a slope of 2 representing TPA.

The outcome of this summer internship will help the UP group to implement the TPA detector as a means of detection in their OSCAT setup, in a similar approach to previously reported in [1]. OSCAT means optical sampling by laser cavity tuning and can be used as a high-speed optical sampling method to conduct, for example pump-probe spectroscopy of ultrafast phenomena lasting for picoseconds, with very short acquisition times of the order of microseconds or less. Due to the short acquisition time the process can potentially be used to detect various dynamic characteristics of the sample as they are changing, such as sub-µm changes in distance, alternating temperatures in a sample or very fast processes in gases or liquids, such as combustion processes.

Finally, I would like to thank the UP Group for their support and the great experience I had during this summer project.

[1] Lin Yang, Jinsong Nie, and Lingze Duan, "Dynamic optical sampling by cavity tuning and its application in lidar," Opt. Express 21, 3850-3860 (2013)

Stepping into the World of Biophysics

Euan Millar, 4th Year Physics Student, Grace Swinton, 4th Year Physics Student

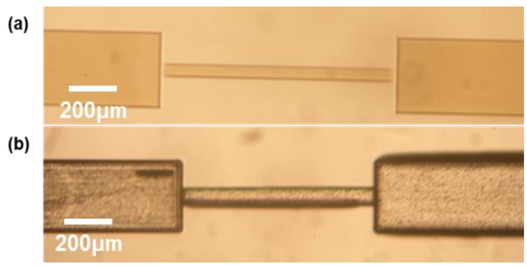

*Fig 1. Images of 50µm wide microfluidic channel with 300µm wide inlet and outlet, written at 2mm/s at 340mW with horizontal polarisation **(a)** before etching in KOH and **(b)** after etching in KOH.*

Over summer we worked as part of the Biophotonics group with Dr Lynn Paterson. During this internship we explored two research avenues pertaining to the study of cells and their behaviour.

The first project we worked on aimed to model the microvasculature. This field of research is of particular interest to those working in the life sciences as constrictions in blood vessels can lead to red blood cell partitioning at bifurcations, giving rise to tumour tissue hypoxia [1]. These channels were created using Ultrafast Laser Inscription (ULI) – a technique in which the incident laser light produces modifications in the substrate – in this case a 1cm x 1cm x 2mm chip of fused silica) by multiphoton processes [2], followed by selective chemical etching.

The chip was adhered to a mechanical stage, with its three-dimensional movements controlled by a G-code program to map different lines and channels. The stage translated underneath the fixed laser, modifying specified regions of the glass. After inscription, potassium hydroxide (KOH) was employed as an etchant to remove material from the modified regions of substrate. When the glass chips were submerged in KOH, the modified regions etched away faster than the unmodified regions, leaving channels in the glass.

To successfully write a microfluidic channel, writing parameters such as polarisation, write speed and power, were optimised to ensure the KOH etched as efficiently as possible. After several etch tests, the optimised setup was used to write a 50µm channel with 300µm inlets, depicted in fig. 1. These inlets were created to allow tubing to be attached to the device to enable cells to flow through the channel.

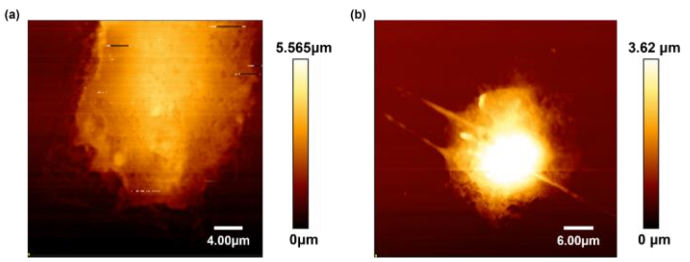

*Fig 2. Height measurements of macrophages cultured in **(a)** FBS and **(b)** a human derived culturing medium.*

Building on this work, the Biophotonics group can employ these processes to model bifurcated channels with constrictions as a means to experimentally study microvasculature and its link to tumour hypoxia.

The second project focused on examining the biomechanical properties of cells using Atomic Force Microscopy (AFM), a form of scanning probe microscopy. This provided a means to study the surface structures of samples with very high resolution and accuracy [3]. The apparatus employed a sharp tip mounted to the end of a cantilever to scan across the surface of samples. A laser, aligned to the end of the cantilever, tracked deflections arising from a raised surface, resulting in small deviations in the lasers position. These movements were tracked on a quadrant photodetector, allowing the surface features of the sample to be recorded. This process returned the height and adhesion of samples, and a 'force curve' for each pixel of the image [4].

The setup was used to examine the structural differences between two samples of macrophages cultured in different environments: one grown in Foetal Bovine Serum (FBS) and the other grown in a human derived serum – fig 2. Due to limited time constraints, the analysis performed did not reveal any great contrast between the two cell cultures, though ongoing work in this department aims to explore this further.

To conclude this project; a sample of E. Coli was imaged successfully, facilitating further research opportunities into the phage that infect bacteria as a means to study treatments for antibiotic-resistant infections.

This project was a fantastic experience that allowed us to explore the interdisciplinary impact of physics in the wider scientific community. It also provided a very beneficial opportunity to gain experience in multiple labs, all specialising in different fields of research.

We would also like to thank Rank Prize Funds and Heriot-Watt University for funding our vacation scholarships.

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[2] Mackenzie, M. D. Microfluidic Devices and Biological Lasers for Biophotonic Applications. Doctor of Philosophy thesis, Heriot-Watt University, 2017.

[3] Eaton, P. & West, P. Atomic Force Microscopy. Oxford University Press (2010).

[4] Giessibl, F. J. Advances in atomic force microscopy. Reviews of Modern Physics 75, 949-983 (2003).

List of Latest Reseach Output

Soliton self-compression and resonant dispersive wave emission in higher-order modes of a hollow capillary fibre.
Brahms, C., & Travers, J. C. (2022).
In JPhys Photonics, 4(3), [034002]. https://doi.org/10.1088/2515-7647/ac6345

N-photon bundle statistics on different solid-state platforms.
Cosacchi, M., Mielnik-Pyszczorski, A., Seidelmann, T., Cygorek, M., Vagov, A., Reiter, D. E., & Axt, V. M. (2022).
In Physical Review B, 106(11), [115304]. https://doi.org/10.1103/PhysRevB.106.115304

A low-cost, open-source centrifuge adaptor for separating large volume clinical blood samples.
Haque, M. E., Marriott, L., Naeem, N., Henry, T., Conde, A. J., & Kersaudy-Kerhoas, M. (2022).
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Valence shell electronically excited states of imidazole and 1-methylimidazole.
Holland, D. M. P., Shaw, D. A., Townsend, D., & Powis, I. (2022).
In Molecular Physics, [e2122614]. https://doi.org/10.1080/00268976.2022.2122614

Color-selective three-dimensional polarization structures.
Intaravanne, Y., Wang, R., Ahmed, H., Ming, Y., Zheng, Y., Zhou, Z-K., Li, Z., Chen, S., Zhang, S., & Chen, X. (2022).
In Light: Science and Applications, 11, [302]. https://doi.org/10.1038/s41377-022-00961-y

Barriers to macroscopic superfluidity and insulation in a 2D Aubry-André model.
Johnstone, D., Öhberg, P., & Duncan, C. W. (2022).
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Bulk localized transport states in infinite and finite quasicrystals via magnetic aperiodicity.
Johnstone, D., Colbrook, M. J., Nielsen, A. E. B., Öhberg, P., & Duncan, C. W. (2022).
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Convergence of combinatorial gravity.
Kelly, C., Biancalana, F., & Trugenberger, C. (2022).
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Spectroscopic application of few-femtosecond deep-ultraviolet laser pulses from resonant dispersive wave emission in a hollow capillary fibre.
Kotsina, N., Brahms, C., Jackson, S. L., Travers, J. C., & Townsend, D. (2022).
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Superconducting pairing from repulsive interactions of fermions in a flat-band system.
Mahyaeh, I., Köhler, T., Black-Schaffer, A. M., & Kantian, A. (2022).
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Quantum researcher mobility: The wonderful wizard of Oz who paid for Dorothy's visa fees.
Malik, M., Agudelo, E., & Kunjwal, R. (2022).
In Quantum Science and Technology, 7(3), [034005]. https://doi.org/10.1088/2058-9565/ac77b3

Ultrafast laser inscription of efficient volume Bragg gratings deep in fused silica using active wavefront shaping.
McArthur, S. R., Siliprandi, J., Maclachlan, D. G., Benoît, A., Thomson, R. R., & Ross, C. A. (2022).
In Optical Materials Express, 12(9), 3589-3599. https://doi.org/10.1364/OME.462654

Frequency-bin entanglement from domain-engineered down-conversion.
Morrison, C. L., Graffitti, F., Barrow, P., Pickston, A., Ho, J., & Fedrizzi, A. (2022).
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Utilizing broadband wavelength-division multiplexing capabilities of hollow-core fiber for quantum communications.
Nasti, U., Sakr, H., Davidson, I. A., Poletti, F., & Donaldson, R. J. (2022).
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Single-Step Fabricable Flexible Metadisplays for Sensitive Chemical/Biomedical Packaging Security and Beyond.
Naveed, M. A., Kim, J., Ansari, M. A., Kim, I., Massoud, Y., Kim, J., Oh, D. K., Badloe, T., Lee, J., Kim, Y., Jeon, D., Choi, J., Zubair, M., Mehmood, M. Q., & Rho, J. (2022).
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Three-element, self-starting Kerr-lens-modelocked 1-GHz Ti:sapphire oscillator pumped by a single laser diode.
Ostapenko, H., Mitchell, T., Castro, P., & Reid, D. T. (2022).
In Optics Express, 30(22), 39624-39630. https://doi.org/10.1364/OE.472533

Picosecond pulsed squeezing in thin-film lithium niobate strip-loaded waveguides at telecommunication wavelengths.
Peace, D., Zappacosta, A., Cernansky, R., Haylock, B., Boes, A., Mitchell, A., & Lobino, M. (2022).
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Storage and analysis of light-matter entanglement in a fiber-integrated system.
Rakonjac, J. V., Corrielli, G., Lago-Rivera, D., Seri, A., Mazzera, M., Grandi, S., Osellame, R., & de Riedmatten, H. (2022).
In Science Advances, 8(27), [abn3919]. https://doi.org/10.1126/sciadv.abn3919

The laws of physics do not prohibit counterfactual communication.
Salih, H., McCutcheon, W., Hance, J. R., & Rarity, J. (2022).
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Tomographic reconstruction techniques optimized for velocity-map imaging applications.
Sparling, C., & Townsend, D. (2022).
In Journal of Chemical Physics, 157(11), [114201]. https://doi.org/10.1063/5.0101789

Tri-mode optical biopsy probe with fluorescence endomicroscopy, Raman spectroscopy, and time-resolved fluorescence spectroscopy.
Wood, H. A. C., Ehrlich, K., Yerolatsitis, S., Kufcsák, A., Quinn, T. M., Fernandes, S., Norberg, D., Jenkins, N. C., Young, V., Young, I., Hamilton, K., Seth, S., Akram, A., Thomson, R. R., Finlayson, K., Dhaliwal, K., & Stone, J. M. (2022).
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