Amplification of magneto-optical activity via hybridization with dark plasmons

Paolo Vavassori[1,2,], Mario Zapata-Herrera[1], Andrey Chuvilin[1,2], Alberto López-Ortega[,3], Nicolò Maccaferri[4], Matteo Pancaldi[5]*,

[1] CIC nanoGUNE BRTA, Donostia–San Sebastian 20018, Spain

[2]IKERBASQUE, Basque Foundation for Science, Bilbao 48013, Spain

[3] Universidad Pública de Navarra, Campus de Arrosadía, Pamplona 31006, Spain

[4] Umeå University, Sweden and University of Luxembourg

[5] Elettra Synchrotron Trieste, AREA Science Park 34149 Basovizza, Trieste, Italy

* p.vavassori@nanogune.e

Summary

Magneto-optical effects are widely used in studying technologically relevant magnetic materials as well as to realize optical devices exploiting non-reciprocal propagation of light. The rapidly developing field of magnetoplasmonics merges the concepts from plasmonics and magneto-optics to realize novel phenomena and functionalities for the manipulation of light at the nanoscale. Owing to the intertwined optical and magneto optical properties, magnetoplasmonics may offer a smart toolbox for actively tunable optical ultrathin surfaces and metasurfaces. Enhancing magneto-optical effects is crucial for size reduction of key photonic devices based on non-reciprocal propagation of light and to enable active nanophotonics. Here, we disclose an approach that exploits dark plasmons to achieve an unprecedented amplification of magneto-optical activity. We designed and realized a symmetry broken non concentric magnetoplasmonic-disk/plasmonic-ring nanocavity fabricated by e-beam lithography. The broken symmetry enables the free-space light excitation of dark multipolar modes in the plasmonic-nanoring and their hybridization with the dipolar plasmonic resonance of the magnetoplasmonic nanoantenna. Such hybridization gives rise to a multipolar Fano resonance that, when excited, produces a large amplification of the magneto-optic response of the nanocavity, which is ~1-order of magnitude higher than the maximum amplification that can be achieved by localized plasmons in a bare magnetoplasmonic nanoantenna. Such large amplification is explained as due to the peculiar and enhanced electrodynamics of the nanocavity, yielding a large magnetically-activated radiant magneto-optical dipole driven by the intense but low radiant multipolar resonance mode, as confirmed by EELS spectroscopy and detailed numerical simulations.
The concept proposed here is general and offers prospects for even higher enhancements via optimization of the nanocavity design. Altogether, our results open a new and fresh path that can revitalize the research and the applications of magnetoplasmonics to active nanophotonics, flat optics, and sensing.

Results and discussion

Enhancing magneto-optical effects is crucial for the size reduction of key photonic devices based on non-reciprocal propagation of light and to enable active nanophotonics. In this work, we propose and experimentally demonstrate a novel conceptual pathway to boost magnetization-induced polarization modulation using multipolar dark plasmon modes in asymmetric magnetoplasmonic nanocavities. This new conceptual design could lead to broad applications in optical communications, sensing, and imaging.
Nanophotonics uses light polarization as an information carrier in optical communications, sensing, and imaging. Likewise, the state of polarization of light plays a key role in the photonic transfer of quantum information. In this framework, optical nanodevices enabling dynamic manipulation of light polarization at the nanoscale are key components for future nanophotonic applications.

Magnetic materials exhibit the so-called magneto-optical (MO) activity, arising from spin-orbit coupling of electrons, which results in a weak magnetic-field-induced intensity and polarization modulation (in the order of mrads) of reflected and transmitted light.

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Magneto-plasmonics explores nanostructures and metamaterials that combine the strong local enhancements of electromagnetic fields produced by localized plasmon excitations, i.e., collective oscillations of the quasi-free electrons, with the inherent MO activity of the magnetic constituent to enhance the otherwise weak magnetic field-induced polarization modulation [1,2].

Up to now, most studies on magneto-plasmonics focused on the excitation of bright (i.e. radiant) localized dipolar plasmonic resonances, known as LPRs, to amplify the MO response [3-5]. Indeed, dimeric and multilayered hybrid noble/ferromagnetic metals structures as well as purely ferromagnetic nanoantennae have demonstrated the possibility to control and amplify the MO properties via plasmonic excitations. For instance, considering the archetypical case of a circular disk-like magneto-plasmonic nanoantenna, incident radiation of proper wavelength excites an LPR (***Po*** in the bottom-center panel of **Figure 1**). When the nanoantenna is "activated" by a magnetic-field (H), a second LPR is induced by the inherent MO activity (***PMO*** in in the bottom-center panel of **Figure 1**). This MO-induced LPR (or MOLPR) is driven by the LPR in a direction orthogonal to both H and the LPR. The ratio between the MOLPR and the LPR corresponds to the ratio between the response of orthogonal radiating electric dipoles that determine the magnetic-field induced polarization change of re-emitted light [1]. However, the generation of a large MO-induced electric dipole associated to the MOLPR results from a parallel enhancement of the electric dipole associated to the LPR. The simultaneous excitation of the LPR, radiating light with the incident polarization, and MOLPR, radiating light with a polarization orthogonal to the incident radiation, limits the maximum achievable enhancement of magnetic-field activated change in polarization of reflected and transmitted light. Due to this limitation of the MO enhancement exploiting bright dipolar resonances, amplifications up to about only 1-order of magnitude of the MO response have been observed experimentally, which are not enough for practical applications of magneto-plasmonics to active nanophotonics and flat-optics as well as sensing.

In this work we unveil and demonstrate experimentally a strategy to overcome the aforementioned limitation based on the excitation of hybrid high order multi-polar dark modes as a viable and powerful mean to amplify the magneto-optical activity of magneto-plasmonic nanoantennas and achieve an unprecedented active control of the light polarization under a magnetic field [6]. We had designed a symmetry broken non-concentric magneto-plasmonic-disk/plasmonic-ring nanostructures (see **Figure 1**) in order to enable the free-space light excitation of multipolar dark modes in the plasmonic-ring as well as their hybridization with the dipolar plasmonic resonance of the magneto-plasmonic disk, leading to a hybrid multipolar mode (see the optical response and the simulated electrodynamics in the top panel of **Figure 1**). The large amplification of the MO response observed for our nanocavity (bottom-left panel in **Figure 1**) is the result of a strongly enhanced *radiant* MOLPR, which is driven by the *low-radiant* hybrid multipolar resonance instead of a bright LPR (see bottom-center and -right panels in **Figure 1**). In this way the amplification of the radiated light from the strongly amplified MO response is achieved avoiding a simultaneous large enhancement of radiated light with the incident polarization.

In conclusion, we have demonstrated that high-order multi-polar dark plasmon resonances in magnetoplasmonic nanocavities can be utilized to achieve unprecedented enhancement of the magneto-activated optical response, beyond the present limitations of magnetoplasmonic nanoantennas, enabling a far more efficient active control of the light polarization under weak magnetic fields. The novel concept unveiled here opens a fresh path towards applications of magnetoplasmonics to a variety of fields ranging from flat and active nanophotonics to sensing. Indeed, the underlying mechanism leading to the enhanced MOA presented in this work suggests a multitude of directions (materials combinations, geometries, and arrangements of the individual units) to be explored to go beyond this proof-of-principle study.

References

[1] N. Maccaferri et al., Phys. Rev. Lett. **111**, 167401 (2013).
[2] K. Lodewijks et al., Nano Lett. **14**, 7207 (2014).
[3] N. Maccaferri et al., Nature Commun. **6**, 6150 (2015).
[4] N. Maccaferri et al., Nano Lett. **16**, 2533 (2016).
[5] I. Zubritskaya et al., Nano Lett. **18**, 302 (2018).
[6] A. López-Ortega et al., Light: Science&Applications **9**, 49 (2020).

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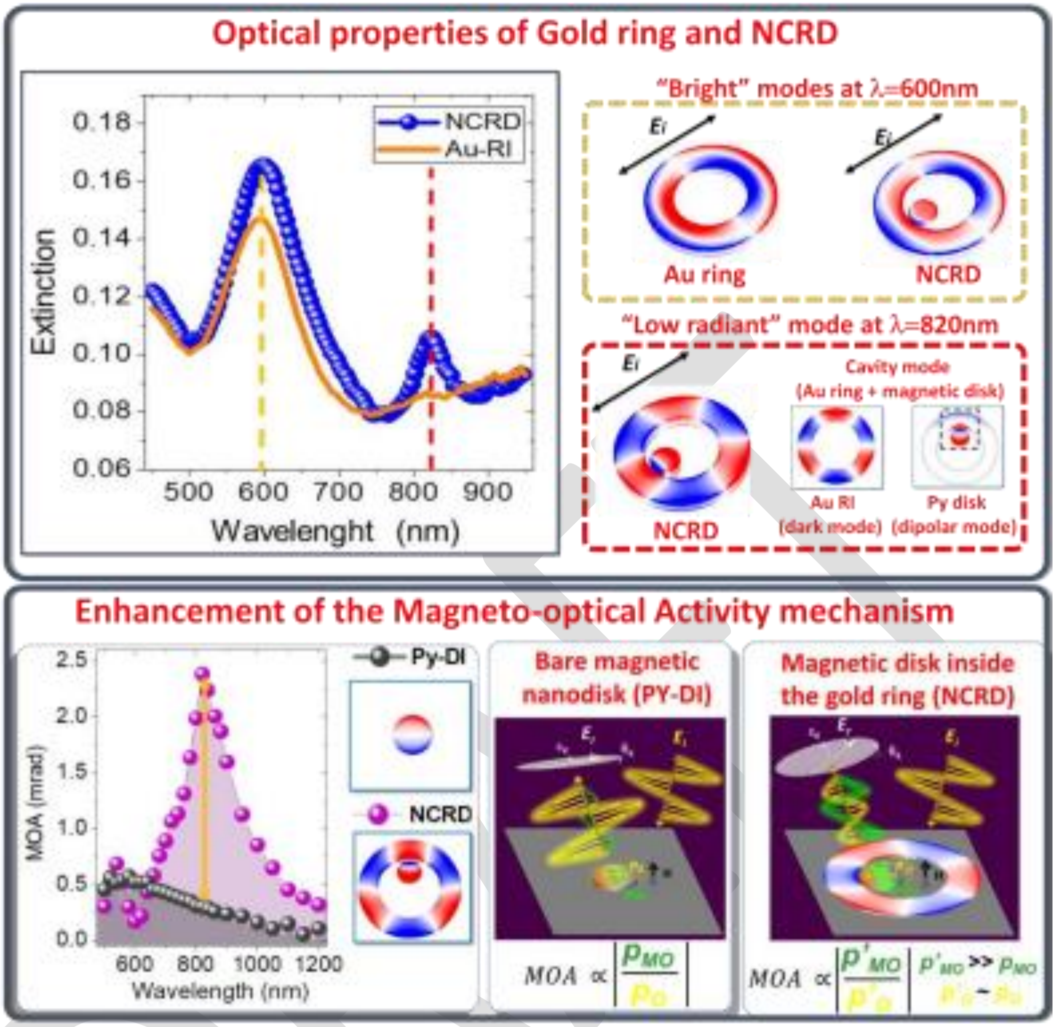

Figure 1: Illustration of the resonant mechanism leading to the large Magneto-optical enhancement in the NCRD nanocavity at resonance maximum.

Sketch of the electrodynamics of the bare magnetic permalloy disk (Py-DI) generating an electric dipole (p_O) triggered by the electric field Ei of an incident linearly polarized electromagnetic radiation and a magneto-optically activated electric dipole (p_{MO}) by a magnetic field H. $p_O$and p_{MO} of the Py nanoantenna inside the Non-Concentric Ring Disk nanocavity (NRCD) are enhanced (by a factor of ~5) with respect to a bare Py disk by hybridization with the dark mode of the gold ring (Au-RI). This is qualitatively depicted by the relative size of electric dipoles p_O and p_{MO} in the Py-DI, and in the NCRD. In the NCRD nanocavity, hybridization generates a hybrid multipolar mode with a weak dipolar dipolar component $p_{O'}$. In the Py-DI system both p_O and p_{MO} are generated by radiant (bright) LPR modes and the resulting H-induced polarization change in the reflected radiation, Er, is determined by their ratio (MOA $\propto$ $|p_{MO}|/|p_O|$). The large enhancement of the H-induced polarization change in the NCDR system is a consequence of the low-radiant character of the hybrid multipolar mode due to the weak dipolar component $p_{O'}$, whilst p_{MO} is strongly enhanced and has a radiant character.

Detection of Ethanol Gas and Study of Signal to Noise Ratio in a Au/Co/Au MOSPR Sensor

Hiromasa Shimizu, and Shoma Suzuki
Department of Electrical and Electronic Engineering,
Tokyo University of Agriculture and Technology
Tokyo, Japan
h-shmz@cc.tuat.ac.jp

***Abstract*—We report detection of ethanol gas by using transverse magneto-optical Kerr effect (TMOKE) in a Au/Co/Au magneto-optical surface plasmon resonance (MOSPR) sensor, and comparison of sensitivity, signal-to-noise-ratio and measurable concentration range. Ethanol gas with a concentration of 1% was detected without reaction layer.**

Keywords—TMOKE; MOSPR; gas sensor; Volatile organic compound; signal-to-noise-ratio

I. Introduction

Surface plasmon resonance (SPR) sensors have been applied to biochemical sensors in aqueous solution with compact size, high throughput and label-free detection. On the other hand, applications to gas sensor including detection of volatile organic compound (VOC) are limited [1]. Highly sensitive detection of VOCs are important in the fields of security, healthcare, biomedical applications, environmental monitoring, agriculture, and food industry. Higher refractive index sensitivity is necessary for gas sensors owing to the smaller molecular weight. For this purpose, magneto-optical surface plasmon resonance (MOSPR) sensors have been reported by using multilayered metal transducers containing ferromagnetic metals and noble metals. Detection of hydrogen gas with concentration of 0.5 ~ 3% has been reported by using polar magneto-optical Kerr effect with a Pd reaction layer [2]. Detection of Helium and Butane with a concentration of 100% has been reported by using transverse magneto-optical Kerr effect (TMOKE) without reaction layers [3]. Reports on detection of VOC with MOSPR sensors are limited and in progress. In this paper, we report detection of ethanol gas as a prototype of VOC detection by using TMOKE in a transducers composed of a Au/Co/Au thin film without reaction layers and comparison of the signal to noise ratio.

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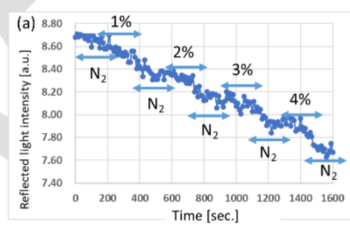
II. Experiment

We prepared an SPR transducer formed of a Au (5 nm) / Co (3 nm) / Au trilayer on a glass substrate mounted on a quartz prism. The thicknesses of the bottom Au thin film are set to 16 and 26 nm in the separate part of the same substrate by using electron-beam evaporation process with the position of the shutter controlled [4]. Alternating magnetic field of a frequency of 104 Hz was applied by a coil along in-plane direction of the substrate, and TMOKE intensity as well as reflected light intensity for p-polarized light was detected by a lock-in technique. Fig. 1 show the transition of the reflected light intensity and TMOKE intensity upon the ethanol gas injection with concentrations of 1, 2, 3, and 4 % in volume with a flow rate of 1 L/min., and N_2 as a carrier gas. Concentrations larger than 2 % were detected with reflected light intensity. Concentrations between 1 and 2 % were detected with TMOKE intensity, whereas concentrations of 3 and 4 % were not detected, indicating higher sensitivity and signal-to-noise-ratio, but limited concentration range by using TMOKE intensity showing higher figure of merit than that with reflectivity.



III. Conclusions

We reported detection of 1% ethanol gas in a Au/Co/Au on a glass substrate without reaction layers and better signal to noise ratio with TMOKE. By incorporating gas

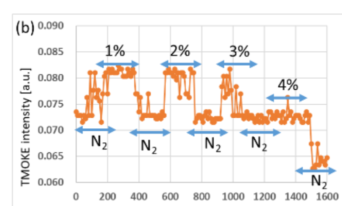


Fig. 1 Transition of (a) the reflected light intensity and (b) TMOKE intensity upon the ethanol gas injection with concentrations of 1, 2, 3, and 4 %.

reaction layers for adsorbing gas molecules, higher gas sensitivity will be realized for VOC detection.

References

[1] S. Brenet et al., Anal. Chem. **90** 9879 (2018).

[2] H. Yamane, Jpn. J. Appl. Phys. **60** SCCG01 (2021).

[3] D. O. Ignatyeva et al., Scientific Reports **6**, 28077 (2016).

[4] H. Shimizu et al., Frontiers in Nanotechnology **3**, 724528 (2021).

Spin Current Generation by a Surface Plasmon Polariton and Beyond

London, United Kingdom

D. C. Lloyd, K. Elphick, A. Hirohata
Department of Electronic Engineering
University of York
York, United Kingdom
atsufumi.hirohata@york.ac.uk

T. J. Wijaya
Department of Electrical and Electronic
Engineering University of Tokyo
Tokyo, Japan

D. Oue
Department of Physics

M. Matsuo
Kavli Institute for Theoretical Sciences
University of Chinese Academy of Sciences
Beijing, P. R. China

Y. Ito, H. Uchida, M. Inoue
Department of Electrical and Electronic
Information Engineering
Toyohashi University of Technology
Toyohashi, Japan

Surface plasmon polaritons (SPPs) are surface localized electromagnetic waves which can be excited optically using the Otto and Kretschman-Raether arrangements (or their mixture). These arrangements can be achieved by attaching a prism on a metal/insulator bilayer [1]. Recently, the angular momentum conversion between the SPP and electrons was theoretically proposed [2]. In this study, we have experimentally demonstrated a propagating spin current induced by SPPs by measuring the inverse spin Hall effect, proving the interconvertibility between the propagating SPP and a spin current experimentally for the first time.

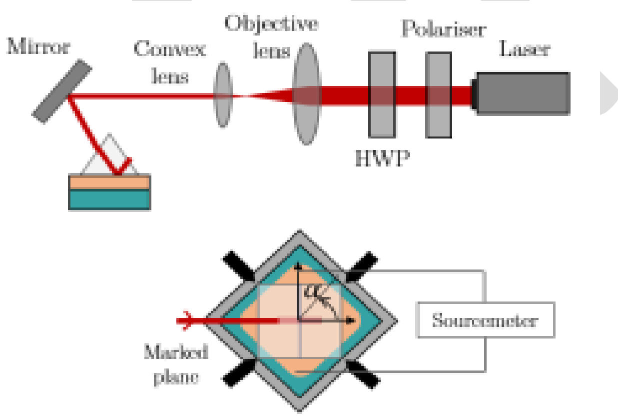


Figure 1. Schematic diagram of the spin current generation by SPP. Angle α indicates sample rotation with respect to its centre.

Imperial College London

The samples were prepared using a high vacuum sputtering system. 20 nm of non-magnetic materials, Ag, Pt and W were sputtered to polycrystalline SiO_2(001) and single-crystal MgO(001) substrates. The schematic diagram of the experimental setup is shown in Fig. 1. The incident angle was adjusted to show the largest Hall voltage in both continuous and Hall bar samples. The spin current generated by the electro
motive force (EMF) I_{emf} was measured . We have successfully measured SPP-induced spin currents unambiguously with the conversion ratio of up to 7%, which can be further improved by optimising the device dimensions [3]. Further improvement of the measurements was achieved by replacing the right-angle prism with a spherical one and by filling the gap between the prism and the sample with optical oil.

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References

[1] J. Sambles *et al.*, *Contemp. Phys.* **32**, 173 (1991).

[2] D. Oue and M. Matsuo, *Phys. Rev. B* **101**, 161404 (2020).

[3] T. J. Wijaya *et al.*, arXiv: 2004.12348.

Sensitivity Measurement of ZnO NPs Prepared With Ixora Coccinea Towards Ammonia Vapour

Rasmita Timalsina[1]* , Leela Pradhan Joshi[1]
[1]Amrit Campus, Institute of Science and Technology Tribhuvan University, Kathmandu, Nepal
*Email: rasmita.765511@ac.tu.edu.np

Abstract: Nanoparticles of zinc oxide were used to prepare thin films for gas sensing applications. The process followed by green synthesis then proceed for a doctor blade method from the mixture paste solution of ZnO nanoparticles with ethanol and few drops of vinegar as binder. As the prepared ZnO coated into the glass substrates were annealed at 400°C. The resistance of these thin films of ZnO were separately measure in air as well as in presence of ammonia vapour in in temperature range (100°C-300°C) and concentration range (40 ppm-200 ppm). The result on sensitivity measurement showed high sensitivity of 72 % at 275°C operating temperature and compared it with without ixora coccinea ZnO NPs by generalizing influence factors.

Keywords: Nanoparticles, Metal Oxide Semiconductor, Green Synthesis, Ixora coccinea, Gas Sensor

Introduction of Metamaterial, and its Application to Enhance the Efficiency of Simultanous Wireless Information and Power Tranfer (SWIPT) System to Biomedical Implants

Ramesh K. Pokharel
I&E Visionaries
Department Kyushu University
Fukuoka, Japan
pokharel@ed.kyushu-u.ac.jp

Adel Barakat
I&E Visionaries
Department Kyushu University
Fukuoka, Japan
barakat@ed.kyushu-u.ac.jp

Near-field Metamaterial-based WPT system can enable over coupling mode by improving the transmitter (TX)/receiver (RX) coupling. The use of a fixed frequency oscillator to supply this system results in poor efficiency when TX/RX distance changes. Instead, we propose the use of a free-running oscillator to track the frequency of peak efficiency when over coupling occurs. Moreover, we employ a frequency hopping technique to enable back-data communication. The proposed WPT system operates at 50MHz and consists of a free-running voltage-controlled oscillator (VCO) operating at 0.6 V voltage supply and an off-chip metamaterial-based LC tank at the transmitter (TX) side. At the receiver (RX) side, the WPT system consists of an off-chip metamaterial-based LC tank, a rectifier, and a transistor operated as a switch for back-data communication, as per our frequency hopping technique. A digital FSK demodulator was designed to demodulate the signal using 0.18µm CMOS technology. Simulation results show that the transmitted data was successfully recovered at the TX side, and thus confirmed the validity of the proposed concept. Fig. 1 illustrates the working principle of FSK (Frequency Shift Keying) modulation technique with the metamaterial-based over coupled WPT system to transfer power and information simultaneously in SWIPT system.

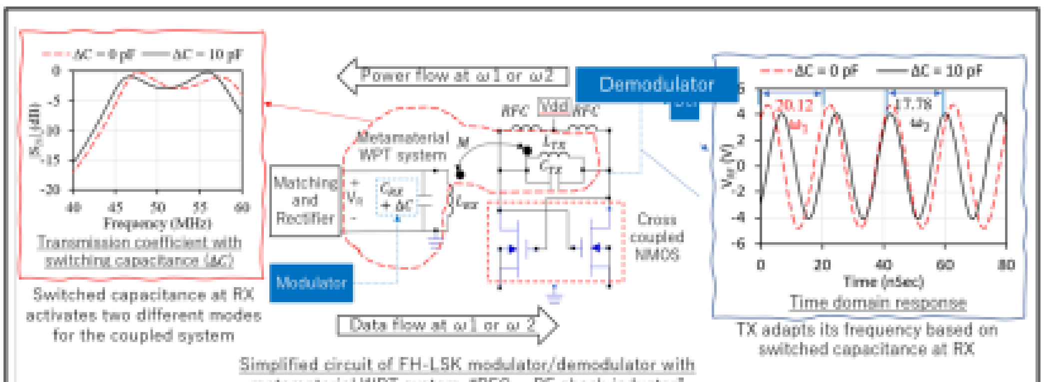

Fig.1: Demonstration of FSK modulation with metamaterial-based WPT system.

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Nanoplasmonics biosensors platfoms for clinical diagnostics at the point-of-care

Laura M. Lechuga
Nanobiosensors and Bioanalytical Applications Group,
Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC, BIST and CIBER-BBN,
Campus UAB, Bellaterra, 08193 Barcelona, Spain
Laura.lechuga@icn2.cat

***Abstract*—Plasmonics biosensing has positioned as a competitive diagnostics technology which is evolving to point-of-care format for real-life applications. We summarized here our work in this area, where we are developing novel plasmonics nanostructures and demonstrating their application in the diagnostics of diseases in a fast, label-free way and using a minimum volume of patient's samples.**

Keywords— nanoplasmonics biosensor; label-free; surface biofunctionalization; Point-of-care.

I. INTRODUCTION (*HEADING 1*)

COVID-19 pandemics has evidenced the urgent need of having portable diagnostic tools that enable rapid testing and screening of the population with sensitivity and specificity levels comparable to laboratory techniques. Biosensor technology is one of the best prepared to tackle the challenging goal of offering fast and user-friendly diagnostics tests than can be employed at the point-of-need. In particular, plasmonics biosensors can provide sensitive, reliable and selective analysis, while reducing test and therapeutic turnaround times, decreasing and/or eliminating sample transport, and using low sample volume. Our main objective is to achieve ultrasensitive Point-of-care (POC) platforms for label-free analysis using plasmonics biosensing technologies and custom-designed biofunctionalization protocols, accomplishing the requirements of disposability and portability.

II. PLASMONICS BIOSENSORS & BIOAPPLICATIONS

We are engineering nanoplasmonics biosensor to attain portable and affordable point-of-care devices with the analytical performance to address the rigorous requirements in clinical diagnostics. Our sensing platforms are compatible with conventional gold films (conventional SPR) and with low-cost, easy to-fabricate metallic nanostructures (gold nanodisks and nanoantenna, fabricated by hole mask colloidal lithography) or with novel nanostructures like metallic (gold and gold/silver) nanoslits obtained from nanostructured substrates (like Blu-ray disc). Current designs (single & multiplexed) show an excellent performance (Limits of detection: 10^{-6} RIU) and has proven to successfully perform in a myriad of challenging clinical applications.

By custom tailoring the biochemistry of the plasmonic biochips, our POC plasmonic biosensor technology can perform direct detection of proteins, genetic biomarkers or pathogens within <15 min, with high sensitivity and selectivity. The diagnostic potential has been demonstrated and validated among others, for the drug monitoring of anticoagulants in plasma, antibiotic allergy diagnosis in plasma, early cancer diagnosis (colorectal and lung cancer) and bacterial, and viral infectious diseases. During COVID-19 pandemic, our POC biosensor has been fully validated with hundreds of clinical samples for the direct detection of anti-SARS-CoV-2 immunoglobulins in COVID-19 patients, confirming excellent diagnostic performance.

III. CONCLUSIONS

The pandemic of COVID-19 has highlighted the need of decentralising clinical diagnostics by implementing new POC technologies. Nanoplasmonics biosensors have demonstrated their superior diagnostics capabilities offering the required sensitivity and selectivity in a myriad of different diseases analyses. The nanoplasmonic biosensor technology is well placed to provide fully operative point-of-care devices for rapid, accurate, and decentralised diagnosis, which can operate at the point-of-need.

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References

1. E. Mauriz, P. Dey and L.M. Lechuga. Advances in Nanoplasmonics biosensors for clinical applications. Analyst 144, 7105-7129 (2019)
2. A. Portela, O. Calvo-Lozano, M.-C. Estévez, L.M. Lechuga. Optical nanogap antennas as plasmonic biosensors for the detection of miRNA biomarkers. Journal of Materials Chemistry B: 'Biosensors'. 8 (19), 4310-4317. (2020)
3. O. Calvo-Lozano,….and L.M. Lechuga. Label-free plasmonic biosensor for rapid, quantitative, and highly sensitive COVID-19 serology: implementation and clinical validation. Anal. Chem. 94, 2, 975-984 (2022)

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Driving motion with light: new technology for magnetometry and biological imaging

W. P. Bowen
Australian Centre for Engineered Quantum Systems
School of Mathematics and Physics, University of Queensland, Queensland, Australia
w.bowen@uq.edu.au

***Abstract*—Cavity optomechanics uses the radiation pressure of light and motion to observe and control motion with exquisite precision. It is applied here to achieve highly sensitive magnetometry and quantum-enhanced bioimaging.**

Keywords— cavity optomechanics; optomechanical sensing; quantum imaging; magnetometry; nonlinear microscopy.

I. Introduction

Cavity optomechanical devices combine optical and mechanical resonances to amplify the radiation pressure interaction between light and mechanical motion. They have applications across length scales from killometres, such as in gravitational wave observatories, to nanometres, such as in single molecule sensing. This presentation will provide an overview of progress optomechanical sensing within my laboratory, focussing on applications in precision magnetometry [1] and biological imaging [2].

II. Cavity Optomechanical Magnetometry

In most configurations of cavity optomechanics, a nanoscale mechanical element is engineered to exhibit very low loss mechanical resonances [3]. By either integrating optical resonances within the same device or placing the device within a high quality optical cavity, it is then possible to precisely observe the motion of the mechanical element through its effect on the amplitude or phase of the light that interacts with it. By designing the mechanical element to response to particular stimuli from the environment, it is possible to create highly sensitive sensors of stimuli ranging from acceleration, to ultrasound, acoustic waves, and temperature. In our laboratory, we have developed cavity optomechanical magnetometers, where the mechanical element is functionalised with a magnetostrictive material that expands in the presence of a magnetic field [1]. This expansion drives mechanical motion, which is enhanced by the mechanical resonance. Through this approach we have achieved magnetic field sensitivity close to the best reported sensitivity in comparably-sized state-of-the-art cryogenic magnetometers (Superconducting Quantum Interference, or SQUID, magnetometers) [1]. By contrast, our magnetometers are fabricated on a silicon chip and require only microwatts of sensor head power. This provides the prospect for a wide range of applications, from precision magnetometers for drones-based sensing and navigation, to lab-on-a-chip NMR and brain imaging.

III. Quantum-enhanced microscopy

An alternative configuration of cavity optomechanics replaces the mechanical element with a vibrational mode of a molecule. Here, the molecule interacts with the optical field via Raman scattering. It has been shown, for instance, that the anomalously large light-scattering observed in surface enhanced Raman scattering may be attributable to optomechanical effects, with plasmon resonances forming the optical cavity and the light-molecule interaction acting to excite the molecule into higher vibrational energy levels. Alternatively, by engineering the quantum state of the light field used to illuminate the molecule, it is possible reduce the noise floor of measurements of the intensity of light that it Raman scatters. I will report recent work from my laboratory that demonstrates this principle, and applies it into quantum-enhanced Raman microscopy [2]. In this work, we utilized quantum *squeezed* states of light to reduce measurement noise beneath the shot noise limit. This allowed us to demonstrate stimulated Raman imaging with contrast beyond the fundamental limits of conventional approaches.

IV. Conclusions

Enhanced radiation pressure interactions between light and mechanical motion offer a pathway to improve a wide range of sensitive measurement technologies. Here, I report applications in magnetometry and biological imaging.

References

1. J.S. Bennett *et al*. Precision Magnetometers for Aerospace Applications: A Review. Sensors **21** 5568

(2021); B.-B. Li *et al.* Ultrabroadband and sensitive cavity optomechanical magnetometry. Photonics Research **8** 1064 (2020).
2. C. Casacio *et al.*. Quantum-enhanced nonlinear microscopy. Nature **594** 201 (2021); L. S. Madsen *et al.* Ultrafast viscosity measurement with ballistic optical tweezers. Nature Photonics **15** 386 (2021).
3. W. P. Bowen and G. J. Milburn, *Quantum optomechanics*, CRC Press (2015).

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Silicon Photonic Neural Networks for Computing and AI

Bhavin J. Shastri
Department of Physics, Engineering Physics & Astronomy, Queen's University, Kingston, ON K7L 3N6, Canada shastri@ieee.org

***Abstract*— Photonics neural networks employ optical device physics for neuron models and optical interconnects for distributed, parallel, and analog processing for high-bandwidth, low-latency, and low switching energy applications in artificial intelligence and neuromorphic computing. We discuss integrated photonics enabled by silicon photonics for machine learning acceleration (inference and training) and neuromorphic computing.**

Keywords— silicon photonics, optical computing, neural networks, machine learning.

Research in photonic computing has flourished with advances in integrated optics enabled by CMOS-compatible silicon photonics, the rise in artificial intelligence (AI) enabled by neural networks models, and programmable analog photonic integrated circuits, neuromorphic (neuron-inspired) photonic systems [1-3]. Photonic integrated circuits have enabled accelerators for tensor cores for matrix multiplications [4-6], neuromorphic computing [7-11], and machine learning inference [12-14]. Algorithms running on such hardware can address the growing demand for machine learning and artificial intelligence in medical diagnosis, telecommunications, and high-performance and scientific computing. In parallel, the development of neuromorphic electronics has highlighted challenges in that domain, mainly related to processor latency. Neuromorphic photonics enabled by silicon photonics offers sub-nanosecond latencies, providing a complementary opportunity to extend the field of artificial intelligence and neuromorphic computing with applications in high-performance computing, nonlinear programming, and intelligent signal processing. We discuss the recent advances in integrated photonic neuromorphic systems discuss current and future challenges.

References

1. Prucnal, Paul R., and Bhavin J. Shastri. Neuromorphic photonics. CRC Press, 2017.
2. Shastri, Bhavin J., et al. "Photonics for artificial intelligence and neuromorphic computing." Nat. Photon. 15.2 (2021): 102-114.
3. Huang, Chaoran, et al. "Prospects and applications of photonic neural networks." *Advances in Physics: X* 7.1 (2022): 1981155.
4. Feldmann, Johannes, et al. "Parallel convolutional processing using an integrated photonic tensor core." *Nature* 589.7840 (2021): 52-58.
5. Miscuglio, Mario, and Volker J. Sorger. "Photonic tensor cores for machine learning." *Applied Physics Reviews* 7.3 (2020): 031404.
6. Bangari, Viraj, et al. "Digital electronics and analog photonics for convolutional neural networks (DEAP-CNNs)." *IEEE Journal of Selected Topics in Quantum Electronics* 26.1 (2019): 1-13.
7. Tait, Alexander N., et al. "Neuromorphic photonic networks using silicon photonic weight banks." Sci. Rep. 7.1 (2017): 1- 10.
8. Shi, B., Calabretta, N. & Stabile, R. Deep neural network through an InP SOA-based photonic integrated cross-connect. IEEE J. Sel. Top. Quantum Electron. 26, 7701111 (2020).
9. Mourgias-Alexandris, G. et al. An all-optical neuron with sigmoid activation function. Opt. Express 27, 9620–9630 (2019).
10. Peng, H. T. et al. Neuromorphic photonic integrated circuits. IEEE J. Sel. Top. Quant. Electron. 24, 6101715 (2018).
11. Tait, Alexander N., et al. "Silicon photonic modulator neuron." Phys. Rev. Appl. 11.6 (2019): 064043.
12. Shen, Yichen, et al. "Deep learning with coherent nanophotonic circuits." Nat. Photon. 11.7 (2017): 441-446
13. Lin, Xing, et al. "All-optical machine learning using diffractive deep neural networks." Science 361.6406 (2018): 1004-1008.
14. Huang, Chaoran, et al. "A silicon photonic–electronic network for fibre nonlinearity compensation." Nature Electronics 4.11 (2021): 837-844.

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Advanced magnetic nanomaterials: patterned antidots, T-shaped nanostructures and nanopillars

Dr. José Miguel García-Martín
Institute of Micro & Nanotechnology (IMN)
Spanish National Research Council (CSIC), Spain
Tres Cantos, Madrid, Spain
josemiguel.garcia.martin@csic.es

***Abstract*—Three different nanomaterials are studied in this contribution: i) magnetic thin films perforated with long-range order arrays of nanoholes prepared by focused ion beam (patterned antidots); ii) T-shaped nanostructures manufactured by electron beam lithography; iii) Large-area nanopillar arrays fabricated by glancing angle deposition with sputtering.**

Keywords—antidots; nanostructures; nanopillars; focused ion beam; electro-beam lithography; sputtering.

I. Patterned Antidots

Magnetic antidots are being studied for different applications, such as magnonic crystals for microwave devices, magnetically-active plasmonic media, magnetic biosensing, and magneto-resistance sensors. In our work, a top-down approach using focused ion beam has been employed to fabricate Co/Permalloy hard-soft bilayer antidot arrays [1]. The antidots have a 40 nm diameter and two symmetries are studied: square and hexagonal. A dependence of magnetic coercivity on the relative thicknesses of the magnetically hard (Co) and soft (Permalloy) layers is found; increasing Permalloy thickness results in lower magnetic coercivity. Furthermore, the long range periodicity of these antidots results in higher magnetic coercivity and a stronger magnetic domain-wall pinning, compared to identical hard/soft bilayers of short-range order deposited on porous anodic alumina. Finally, magnetic force microscopy (MFM) imaging of the antidot arrays shows striking qualitative differences between the two symmetries: square symmetry arrays have inhomogeneous magnetic state and a high density of immobile super-domain walls, whereas hexagonal symmetry arrays show a homogeneous magnetic configuration.

II. T-shaped nanostructures

The study of patterned magnetic elements that can sustain more than one bit of information is an important research line for developing new routes in magnetic storage and logic devices. Previous theoretical studies of T-shaped magnetic nanostructures revealed the equilibrium and evolution of magnetic states that could be found as a result of the strong configurational anisotropy of these systems. In this work, for the first time, such behavior of T-shaped nanostructures is experimentally studied [2]. In particular, T-shaped Co nanostructures have been produced by e-beam lithography using a single step lift-off process. The existence of four magnetic stable states has been proven by MFM and micromagnetic simulations. Therefore, these results confirm that two bits of information can be stored. How to write and read those bits is also addressed.

III. Nanopillars

Glancing angle deposition with magnetron sputtering (MS GLAD) is an easy and versatile route to fabricate arrays of nanostructures in large areas in a single processing step. In our work, nanostructured films with vertical or tilted nanopillars composed by polycrystalline Fe and Fe_2O_3 have been fabricated depending on whether the substrate is kept rotating azimuthally during deposition or not, respectively [3]. The magnetic properties of these films can be tuned with the specific morphology. In particular, the growth performed through a collimator mask mounted onto a not rotating azimuthally substrate produces almost isolated well-defined tilted nanopillars that exhibit a magnetic hardening. The first-order reversal curves diagrams and micromagnetic simulations revealed that a growth-induced uniaxial anisotropy, associated with an anisotropic surface morphology produced by the GLAD in the direction perpendicular to the atomic flux, plays an important role in the observed magnetic signatures.

IV. Conclusions

The combination of antidot symmetry and hard/soft thickness, allow for efficient tailoring of the magnetic properties of nanopatterned thin films. T-shaped nanostructures can sustain two bits of information. Finally, it is shown that the MS-GLAD method is a powerful method to fabricate nanostructured films in large area with tailored structural and magnetic properties for technological applications.

V. Acknowledgements

All the co-authors involved in these three works are acknowledged.

VI. References

[1] Kaidatzis *et al.*, J. Magn. Magn. Mat. **498**, 166142 (2020). [2] Sinnecker *et al.*, Materials **14**, 1567 (2021). [3] Navarro *et al.*, Nanomaterials **12**, 1186 (2022).

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How to become an entrepeneur while being a scientist

Lidia Martínez[1,2]
[1] Instituto de Ciencia de Materiales de Madrid
ICMM-CSIC [2] Nanostine S. L.
Madrid, Spain
lidia.martinez@nanostine.com

Abstract— Being a scientist and decide to be also an entrepreneur is not always easy. In this talk I will tell you my experience.

Keywords— Entrepreneur; nanotechnology; nanoparticles; nanostructured coatings

I. Introduction

As a scientist, sometimes you have an idea that is susceptible for being exploited by the industry. This is especially true in the case when working in nanoscience, where your research needs to push the limits of the already existing techniques for fabrication or characterization. In these situations, you have to decide whether you want to protect this invention with a patent or just keep the know-how. In the case of patent, the following step is to decide if you license the patent to a company/companies or to exploit the idea yourself by creating your own company.

There is no good or bad solution, it is a question of evaluating each individual case and take the decision. There are many factors to consider and it is not possible to generalize. In this talk I will provide my personal vision according to my experience. In particular, I am a scientist of the Spanish National Research Council (CSIC), but I am also co-founder of two spin-off companies and have another patent licensed to a bigger company. With this background, I will present the good things, but also the drawbacks and difficulties found up to now during these years of entrepreneurship. I will put special emphasis in telling my experience with the most recent spin off. Nanostine (www.nanostine.com) is the culmination of more than 15 years of experience working with nanoparticles fabricated in the gas phase, solving several drawbacks found during these years to make this technique suitable for industrial use. Thanks to it, Nanostine is currently able to provide tailored solutions in strategic sectors like aerospace (i.e.: antimultipactor coatings), energy (i.e.: battery electrodes, hydrogen storage) or nanomedicine (i.e.: antibacterial coatings, contrast agents), as it can produce high added value nanoparticles and nanostructured coatings. In comparison with the more extended wet chemistry methods, the gas-phase synthesis produces ligand-free nanoparticles in such way that their surface is pristine, free of surfactants, maximizing then the interaction surface available for the desired application.

II. Acknowledgement

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Feasibility of Using Multilayered Feedforward Deep Neural Network for Predicting Supercontinuum Generation

Montreal, Canada

Abrar Hussain
Dept. of Electrical and Computer Engineering
Concordia University
abrarhussainfahim@gmail.com

Nayem Al Kayed
Dept. of Electrical and Electronic Engineering
Chittagong University of Engineering and

M.R. Karim
Dept. of Electrical and Electronic Engineering
Chittagong Independent University
Chittagong, Bangladesh
Technology
Chittagong, Bangladesh

B.M.A. Rahman
Dept. of Electrical and Electronic Engineering
City University of London
London, United Kingdom

***Abstract*—Recently machine learning and deep learning researchers have predicted the properties of a highly nonlinear optical phenomenon called Supercontinuum (SC) using high-end and complex deep neural networks such as multilayered Deep Neural Networks (DNNs), and Recurrent Neural Networks (RNN). They have used the numerical simulation data for their DNNs and RNN networks input and got excellent prediction results. However, in this work, we have conducted a feasibility test on using DNN for predicting SC using DNN predicted optical properties. For this purpose, we have employed an optical Silicon-rich Silicon Nitride (SRN) waveguide for predicting and analyzing mainly it's effective mode area (A_{eff}), and effective index (n_{eff}) in the wavelength range of 0.65 μm – 3.05 μm, waveguide core width of 1 μm – 5 μm and waveguide height of 0.3 μm – 0.4 μm. We have also compared the results produced from using actual A_{eff} and n_{eff}. It has been found that especially the predicted values of n_{eff} have produced SC which is not very accurate in terms of spectral and temporal spectra.**

***Keywords*— deep neural network; deep learning; supercontinuum generation; integrated photonics; ultrafast nonlinear optics**

Summary Of Work

Over the last couple of years, in photonics, machine learning (ML) techniques (one of it's variants is known as DNN) have employed to improve the state of the art photonics application in optical fiber sensing, laser characterization, quantum communications, imaging and device design. Very recently, research work [2] has been published on optimizing the waveguide's optical parameters using DNN. These DNN techniques have also been used to analyze rogue solitons in supercontinuum generation [3]. This type of research is still at it's infancy and requires more advanced research to confirm that DNN is worth trying to predict this highly nonlinear SC.

In our very initial level work, we have employed three different configurations of multilayered DNN which have been applied on highly nonlinear optical parametric simulated training data of SRN waveguide and then predicted on a separate set of test data, where the DNNs never seen those test data before during training. We predicted effective index (n_{eff}), effective mode area (A_{eff}), nonlinearity (γ) and dispersion (D) parameters using those DNNs. We further predicted SC generation using the predicted data done by DNNs and actual data from numerical simulation. We found that n_{eff} data predicted by DNNs have not predicted the SC accurately as we have realized that n_{eff} data needs to be very precisely predicted upto at least 8 decimal points. To achieve that accuracy level we can work on more deep layers of DNN or simply can use other complex networks such as RNN.

REFERENCES

[1] Chugh, S., Ghosh, S., Gulistan, A., & Rahman, B. M. A. (2019a). Machine learning regression approach to the nanophotonic waveguide analyses. Journal of Lightwave Technology, 37(24), 6080-6089.

[2] Salmela, L., Lapre, C., Dudley, J. M., & Genty, G. (2020). Machine learning analysis of rogue solitons in supercontinuum generation. Scientific reports, 10(1), 1-8.

Colloidally stable magnetite/nanocellulose hybrid for glucose sensing

Chantal T. Tracey
SCAMT Institute
ITMO University
St. Petersburg, Russia

Abstract: A self-indicating magnetite/nanocellulose hybrid for the non-invasive monitoring of blood glucose levels using non-blood body fluids.

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Island operation Mode of Microgrid and Impact on Stability

Mohan Neupane
Electrical & Communication Engineering, Kathmandu University
Kathmandu University, KU
Dhulikhel, Banepa, Nepal
ermohanneupane@hotmail.com

Abstract: the paper has been mainly focused on the developing stage on renewable energy for the local supply as Micro Grid under Island mode due to the more reliability and stability compare to the grid mode operation due consideration of complex protection system arrangement.

Reprogrammable Magnonic Metamaterials

Adekunle Adeyeye
(adekunle.o.adeyeye@durham.ac.uk)
Department of Physics, Durham University,
South Road, Durham DH1 3LE, United Kingdom

Magnonics (the field of science that refers to information transport and processing by spin waves) is among the promising post- CMOS computing technologies in which the spin waves carry the information. This is an emerging area of spintronics as the energy consumption and integration density of the current semiconductor technology is reaching its fundamental limit. Magnonic based devices promise to usher in an era of low power computing where information is carried by the precession of the electrons' spin instead of dissipative translation of their charge. In the last few years, interest in magnonics has grown largely due to advances in nanotechnology which allows shapes of geometrically confined magnonic elements to be fabricated, the development of new advanced experimental techniques for studying high-frequency magnetization dynamics and the potential use of spin waves as information carriers in spintronic applications.

The first part of this talk will focus on design and fabrication strategies for synthesizing reprogrammable magnonic structures and nanomagnetic networks with deterministic magnetic ground states. Reliable reconfiguration between ferromagnetic, antiferromagnetic and ferrimagnetic ground magnetic states will be shown in rhomboid nanomagnets which stabilize to unique ground states upon field initialized along their short axis. In the second part, a novel waveguide consisting of dipolar coupled rhombic shaped nanomagnetic chain that eliminate the requirement of a stand-by power during operation will be presented. It will be shown that our waveguide could be used to send spin wave signal around a corner without any stand-by power. In our design, gating operation is demonstrated by switching the magnetization of single/multiple nanomagnets in the waveguides in order to manipulate the spin wave amplitude at the output. We observed a significant reduction of spin wave amplitude by switching the nanomagnets using microwave current through a coplanar waveguide.

Plasmonic and Magneto-Plasmonic functional materials: the challenge of single molecule detection

Maria Grazia Manera
CNR-IMM
Istituto per la microelettronica e i microsistemi
Lecce, Italy
mariagrazia.manera@cnr.it

Abstract: The research activity developed by the group in the ambit of plasmonic and magneto plasmonic metal nanostructures and their functional characterization as refractive index transducers in chemo/biosensors is reported.