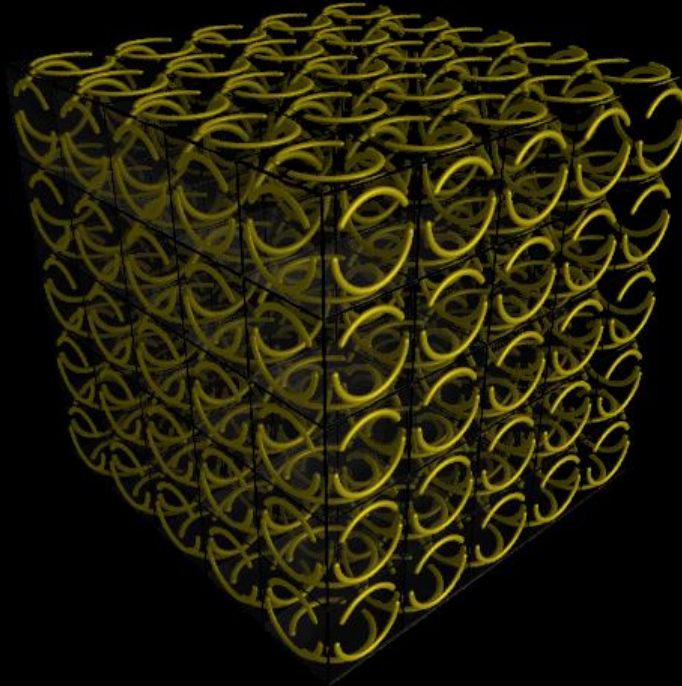


Metamaterials @ Southampton

EPSRC Programme on
“Nanostructured Photonic Metamaterials” + 21 satellite grants
2010-2016

EPSRC Programme on
“The Physics and Technology of Metadevices and Metasystems”
2015 -2021



Developing metamaterials with optical properties on demand

Investigators & Senior Academics

Programme Director



Prof. N. I. Zheludev
(ORC*)



Prof. P. Ashburn
(ECS†)



Prof. R. W. Eason
(ORC)



Prof. D. W. Hewak
(ORC)



Prof. J. Ruostekoski
(Mathematics)



Prof. D. J. Richardson
(ORC)



Prof. B. Hayden
(Chemistry)



Prof. O. Muskens
EPSRC Early Career Fellow
(Physics & Astronomy)



Dr. V. A. Fedotov
*Principal Research Fellow &
EPSRC Career Acceleration
Fellow*
(ORC)



Dr. E. Plum
*Research Lecturer &
Leverhulme Advanced Fellow*
(ORC)



Dr. N. Papisimakis
*Research Lecturer &
Leverhulme Advanced Fellow*
(ORC)



Dr. K. F. MacDonald
*Principal Research Fellow
& Programme Manager*
(ORC)

* ORC = Optoelectronics Research Centre

† ECS = Electronics & Computer Science

Research Staff & Southampton Collaborators

Current Researchers [Jan. 2016]



Dr. J. So
(ORC)

Dr. X. Fang
(ORC)

Dr. V. Savinov
(ORC)

J. Y. Ou
(ORC)

Dr. B. Gholipour
(ORC/Chem.)

Dr. P. Moitra
(ORC)

Affiliated Researchers [Jan. 2016]



Dr. J. Yao
(Chem)

Dr. E. Rogers
(IfLS)

Dr. O. Buchnev
(ORC)

Research Staff Alumni [2010-2015]



Dr. Buckingham
(Physics)

Dr. S. Savo
(ORC)

Dr. T. Uchino
(ECS)

Dr. G. Adamo
(ORC)

Dr. Delfanazari
(ORC/Physics)

Dr. W. Wu
(ORC)

Dr. S. Jenkins
(Maths)

Innovation Project Leaders & Collaborators [2010-2015]



Dr. Ulbricht
(Physics)

Dr. Freearde
(Physics)

Dr. Brocklesby
(ORC)

Prof. Frey
(Chemistry)

Dr. Sazio
(ORC)

Dr. Mailis
(ORC)

Prof. Bartlett
(Chemistry)

Dr. Kanaras
(Physics)

Dr. Huang
(ORC)

Prof. Kaczmarek
(Physics)

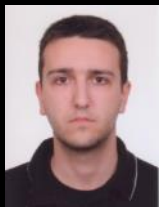
Dr. B. Mills
(ORC)

Students & Visitors

Current Students [Jan. 2016]



J. Valente
(ORC)



E. Atmatzakis
(ORC)



R. Waters
(ORC)



B. Clarke
(ORC)



M. Papaioannou
(ORC)



A. Xomalis
(ORC)



D. Watson
(Maths)



T. Raybould
(ORC)



P. Cencillo Abad
(ORC)



A. Karvounis
(ORC)



D. Piccinotti
(ORC)

Industrial & Academic Visitors



A. Rogacheva
(UK)



M. Tsuruta
(Asahi Kasei, Jpn.)



C. Y. Liao
(NTU, Taiwan)



L. Zhang
(Henan, China)

Former Visitors



Yin
(Singapore)



Wang
(A*)



Hakuta
(Fujifilm)



Shi
(Harbin)



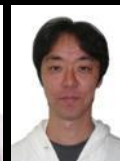
Perino
(Padovay)



Tseng
(Taiwan)



Wu
(Taiwan)



Tanaka
(Sony)



Yasuda
(Fujifilm)



Otsu
(Fujifilm)



Li
(SITP)



Pinheiro
(Brazil)



Kalberer
(Germany)



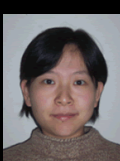
Li
(China)



Bendaña
(CSIC)



Shadrivov
(ANU)



Jia
(Swinburne)



Ren
(Nankai)



Chen
(Taiwan)



Tsai
(Taiwan)



Wang
(Taiwan)



Hiramatsu
(Tokyo)

Completed Students [2010-2015]



J. Y. Ou



V. Savinov



T. Roy



A. Sposito



J. Zhang



B. Gholipour



M. Feinäugle



J. Maddock



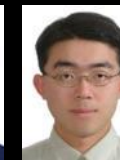
G. Stenning



S. Gregory



A. Tsiatmas



T. S. Kao



Z. Sámson



G. Adamo

Dissemination & Impact

2010-2015

175 Journal articles including

- 32 Nature Group
- 3 Science
- 13 Physical Review Letters
- 8 Advanced (Functional) Materials
- 8 Nano Letters
- 6 ACS Nano / Photonics
- 22 Optics Express
- Phys. Rev., APL, NJP and others

6 Patents

>430 Conference papers including

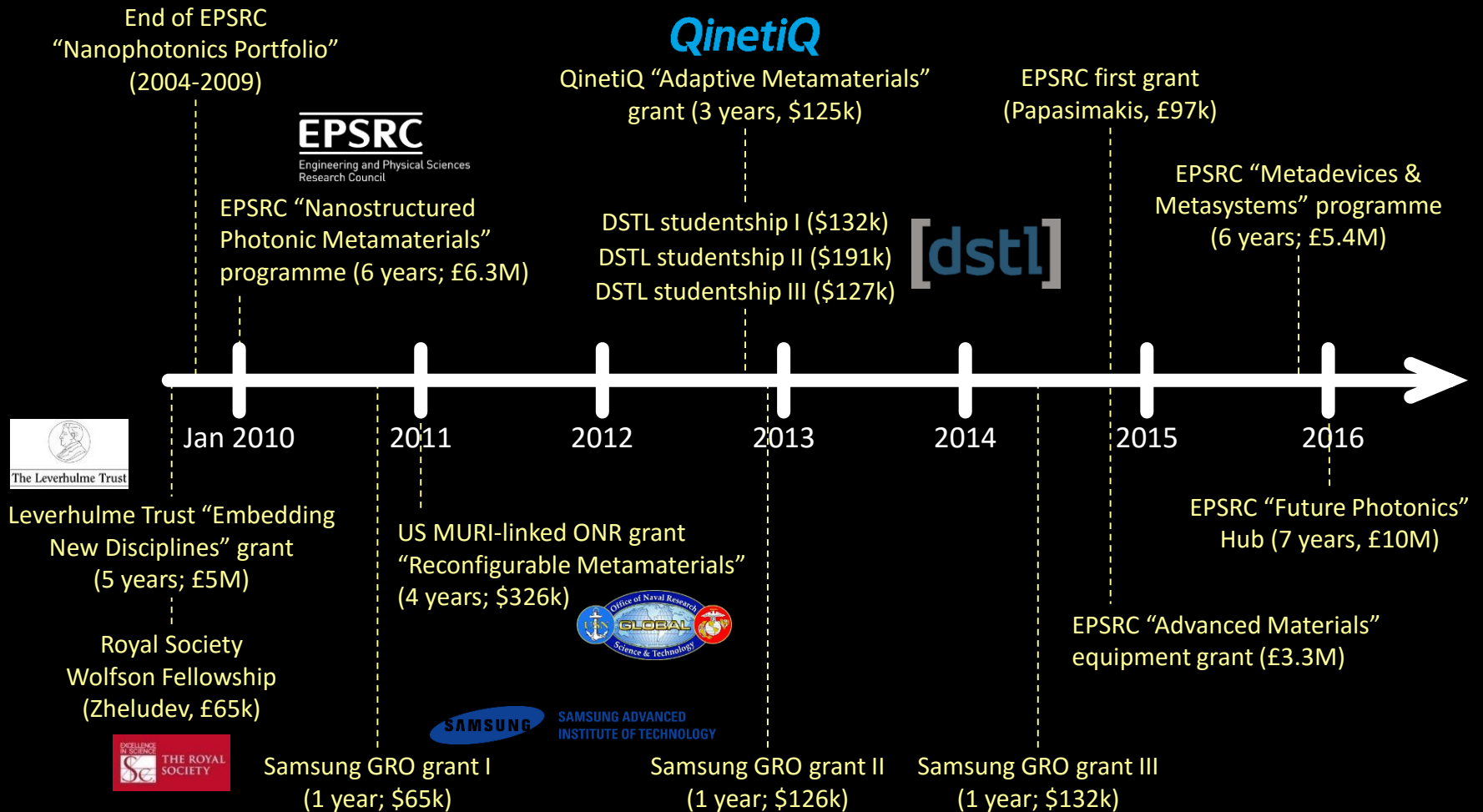
- 20 Plenary
- 27 Keynote
- 123 Invited

Institute of Physics Young Medal 2015



Awarded to Prof. Zheludev for
*“global leadership and pioneering,
seminal work in optical metamaterials
and nanophotonics”*

Timeline & Linked funding



Major International partnerships:

- Southampton – NTU Singapore 'Dual Photonics Centre'
- AFOSR (US) MURI "Active Metasurfaces for Advanced Wavefront Engineering and Waveguiding" [Capasso, et al.; \$6.5M]
- CUDOS-2 "Centre of Excellence for Ultrahigh Bandwidth Devices for Optical Systems" [Eggleton, et al.; AUS \$23M]
- Osaka University Nanophotonics Institute



Nanomechanical Reconfigurable Plasmonic Metamaterials

A magneto-electro-optical effect in a plasmonic nanowire material

J. Valente, J. Y. Ou, E. Plum, I. J. Youngs, and N. I. Zheludev

Nature Commun. **6**, 7021 (2015)

Giant nonlinearity of an optically reconfigurable plasmonic metamaterial

J. Y. Ou, E. Plum, J. Zhang, and N. I. Zheludev

Advanced Materials **28**, 729 (2016)

An electromechanically reconfigurable plasmonic metamaterial operating in the near-infrared

J. Y. Ou, E. Plum, J. Zhang, and N. I. Zheludev

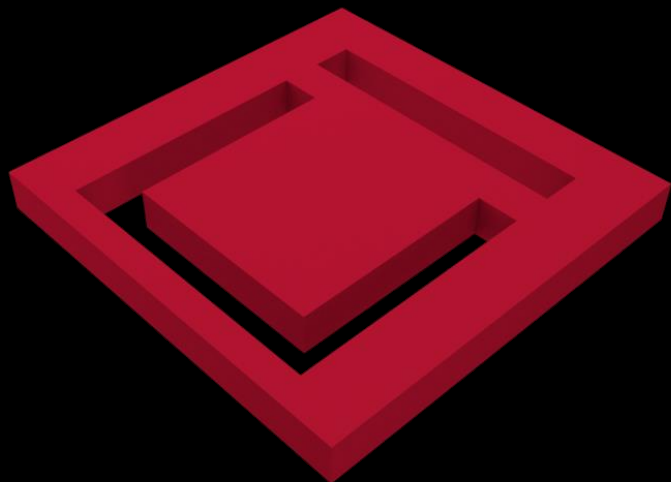
Nature Nanotech. **8**, 252 (2013)

Reconfigurable photonic metamaterials

J. Y. Ou, E. Plum, L. Jiang, and N. I. Zheludev

Nano Letters **11**, 2142 (2011)

Nanomechanical Reconfigurable Dielectric Metamaterials



Reconfigurable nanomechanical photonic metamaterials

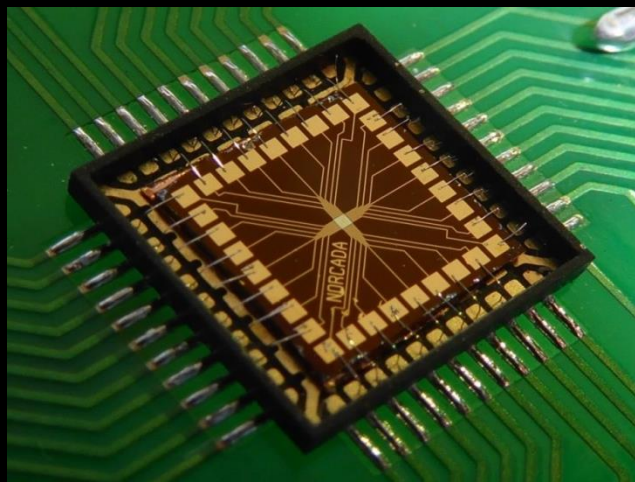
N. I. Zheludev and E. Plum

Nature Nanotech. **11**, 16 (2016)

Nano-optomechanical nonlinear dielectric metamaterials

A. Karvounis, J. Y. Ou, W. Wu, K. F. MacDonald, and N. I. Zheludev

Appl. Phys. Lett. **107**, 191110 (2015)



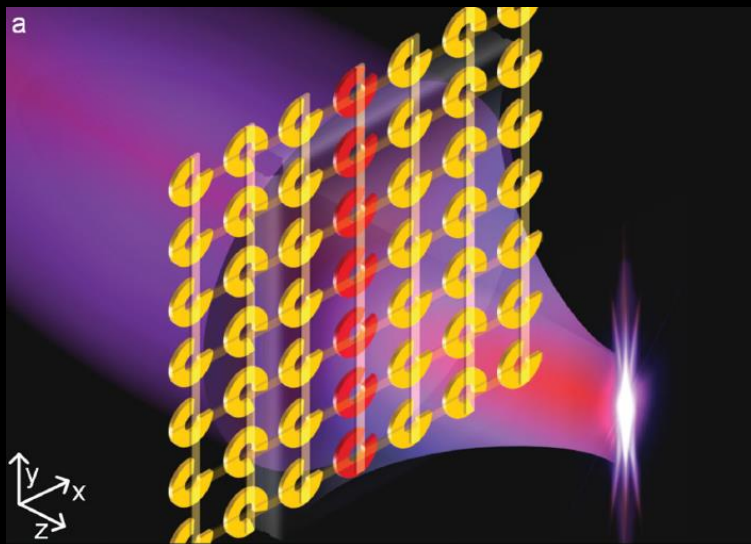
Nonlinear dielectric optomechanical metamaterials

J. Zhang, K. F. MacDonald, and N. I. Zheludev

Nature: Light Sci. Appl. **2**, e96 (2013)

MEMS & Metamaterials

(Singapore collaborations)



A Flat lens with tunable phase gradient by using random access reconfigurable metamaterial

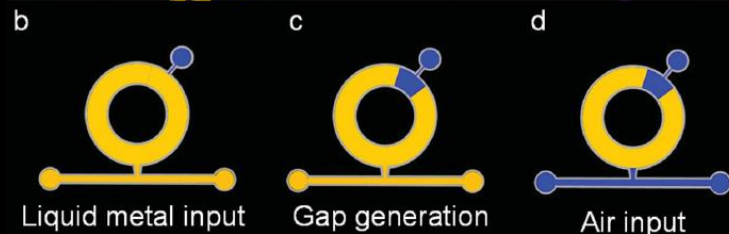
W. M. Zhu, *et al.*

Advanced Materials **27**, 4739 (2015)

Microelectromechanical Maltese-cross metamaterial with tunable terahertz anisotropy

W. M. Zhu, *et al.*

Nature Commun. **3**, 1274 (2012)



A micromachined reconfigurable metamaterial via reconfiguration of asymmetric split-ring resonators

Y. H. Fu, *et al.*

Advanced Func. Materials **25**, 3589 (2011)

Chalcogenide Phase-change Metamaterials

All-dielectric phase-change reconfigurable metasurface

A. Karvounis, *et al.*

Appl. Phys. Lett. (in press)

Optically reconfigurable metasurfaces and photonic devices based on phase change materials

Q. Wang, *et al.*

Nature Photonics **10**, 60 (2016)

1.7 Gbit/inch² gray-scale continuous-phase-change femtosecond image storage

Q. Wang, *et al.*

Appl. Phys. Lett. **104**, 121105 (2014)

Metamaterial electro-optic switch of nanoscale thickness

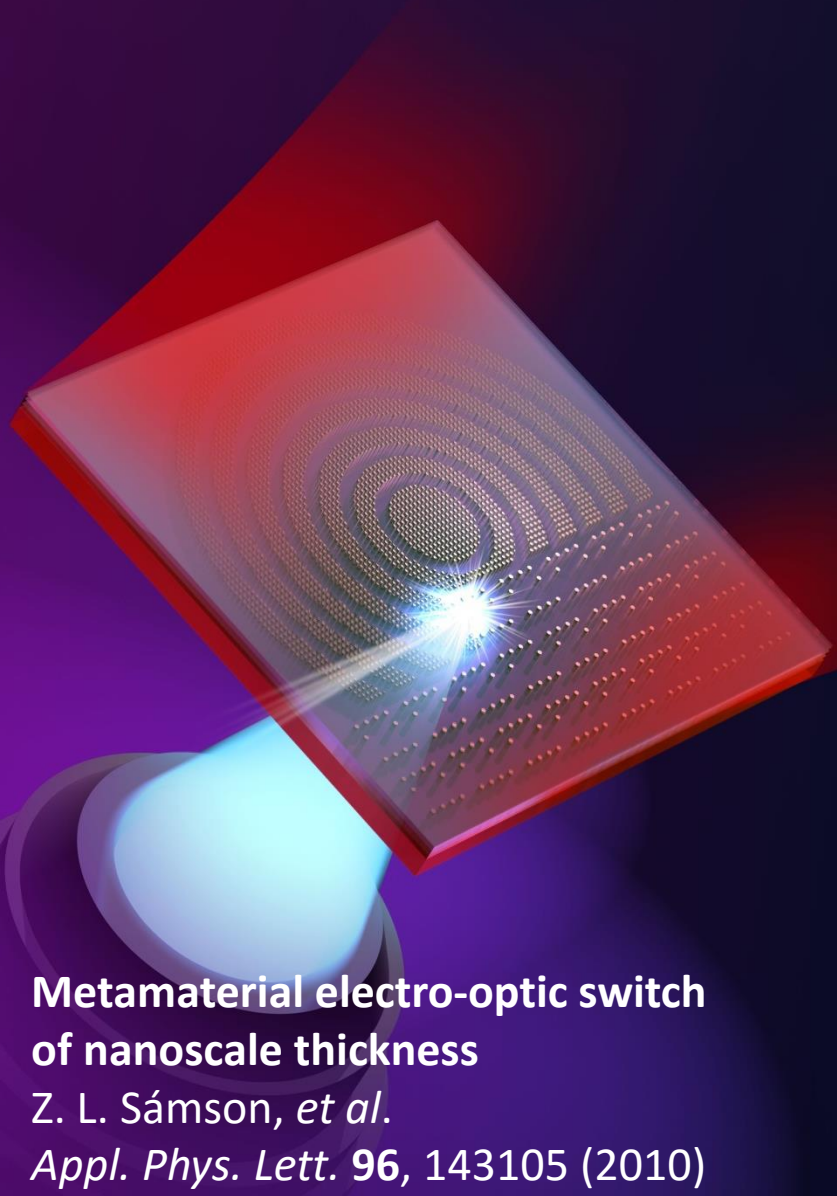
Z. L. Sámsón, *et al.*

Appl. Phys. Lett. **96**, 143105 (2010)

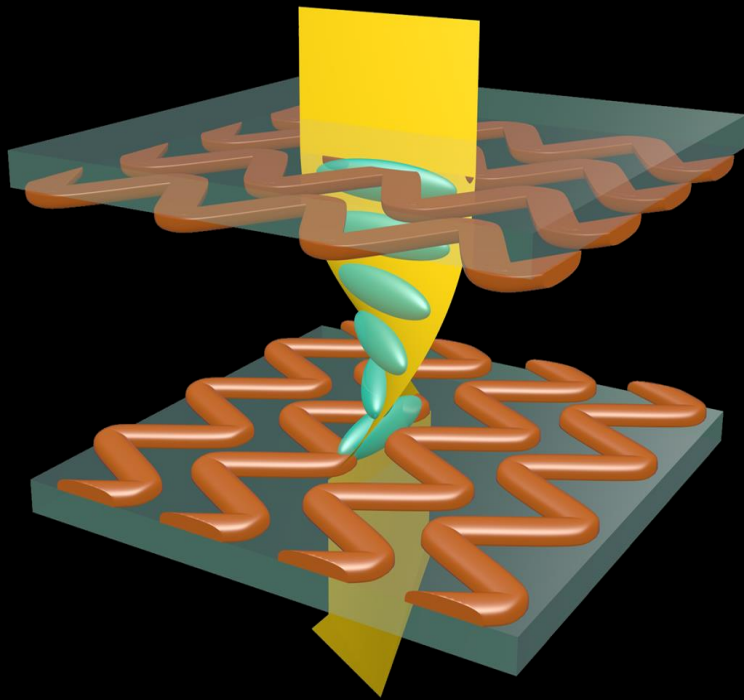
An all-optical, non-volatile, bidirectional, phase-change meta-switch

B. Gholipour, *et al.*

Adv. Mater. **25**, 3050 (2013)



Phase-change Ga & LC Metamaterials



Optically switchable photonic metasurfaces

R. F. Waters, P. A. Hobson, K. F. MacDonald, and
N. I. Zheludev

Appl. Phys. Lett. **107**, 081102 (2015)

Electro-optical control in a plasmonic metamaterial hybridised with a liquid-crystal cell

O. Buchnev, J. Y. Ou, M. Kaczmarek, N. I. Zheludev,
and V. A. Fedotov

Optics Express **21**, 1633 (2013)

Controlling intensity and phase of terahertz radiation with an optically thin liquid crystal- loaded metamaterial

O. Buchnev, J. Wallauer, M. Walther,
M. Kaczmarek, N. I. Zheludev, V. A. Fedotov

Appl. Phys. Lett. **103**, 141904 (2013)

Coherent Control of Metamaterials



Coherent excitation-selective spectroscopy of multipole resonances

X. Fang, *et al.*

Phys. Rev. Appl. **5**, 014010 (2016)

Controlling light with light using coherent metadevices: all-optical transistor, summator and inverter

X. Fang, K. F. MacDonald, and N. I. Zheludev

Nature: Light Sci. Appl. **4**, e292 (2015)

Coherent perfect absorption in deeply subwavelength films in the single-photon regime

T. Roger, *et al.*

Nature Commun. **6**, 7031 (2015)

Controlling light-with-light without nonlinearity

J. Zhang, K. F. MacDonald, and N. I. Zheludev

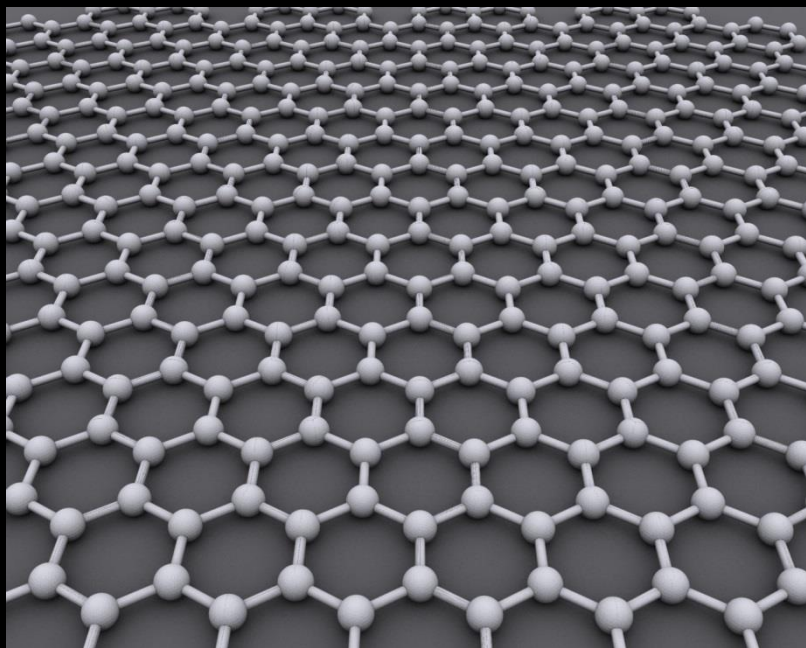
Nature: Light Sci. Appl. **1**, e18 (2012)

Coherent control of birefringence and optical activity

S. A. Mousavi, *et al.*

Appl. Phys. Lett. **105**, 011906 (2014)

2D Materials and Metamaterials



Ultraviolet and visible range plasmonics in the topological insulator $\text{Bi}_{1.5}\text{Sb}_{0.5}\text{Te}_{1.8}\text{Se}_{1.2}$

J. Y. Ou, *et al.*

Nature Commun. **5**, 5139 (2014)

The magnetic response of graphene split-ring metamaterials

N. Papasimakis, *et al.*

Nature: Light Sci. Appl. **2**, e78 (2013)

Nonlinear graphene metamaterial

A. E. Nikolaenko, *et al.*

Appl. Phys. Lett. **100**, 181109 (2012)

Carbon nanotubes in a photonic metamaterial

A. E. Nikolaenko, *et al.*

Phys. Rev. Lett. **104**, 153902 (2010)

Graphene in a photonic metamaterial

N. Papasimakis, *et al.*

Optics Express **18**, 8353 (2010)

Toroidal Metamaterials

Electromagnetic Toroidal Excitations in Matter and Free Space

N. Papasimakis, *et al.*

Nature Materials **15**, 263 (2016)

Dielectric metamaterials with toroidal dipolar response

A. A. Basharin, *et al.*

Phys. Rev. X **5**, 011036 (2015)

Toroidal dipolar excitation and macroscopic electromagnetic properties of metamaterials

V. Savinov, V. A. Fedotov, and N. I. Zheludev

Phys. Rev. B **89**, 205112 (2014)

Resonant transparency and non-trivial non-radiating excitations in toroidal metamaterials

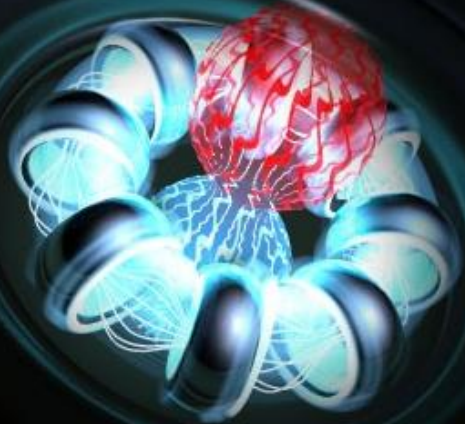
V. A. Fedotov, *et al.*

Scientific Reports **3**, 2967 (2013)

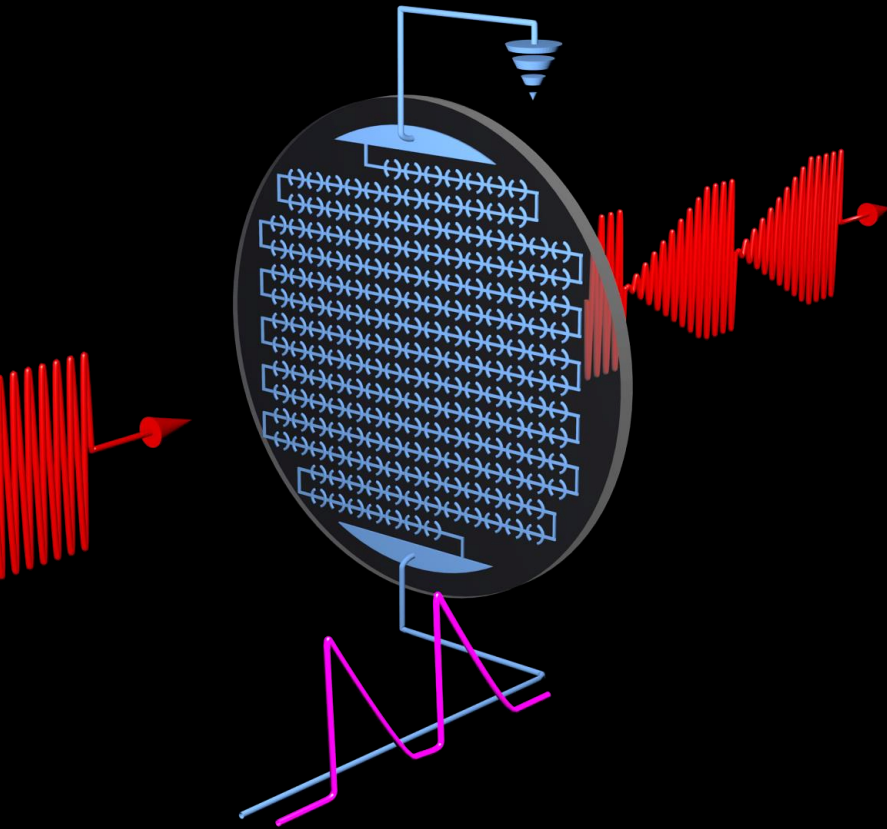
Toroidal dipolar response in a metamaterial

T. Kaelberer, *et al.*

Science **330**, 1510 (2010)



Superconducting Metamaterials



Superconductor photonics

R. Singh and N. I. Zheludev

Nature Photonics **8**, 679 (2014)

Low-loss terahertz superconducting plasmonics

A. Tsiatmas, *et al.*

New J. Phys. **14**, 115006 (2012)

Modulating sub-THz radiation with current in superconducting metamaterial

V. Savinov, *et al.*

Phys. Rev. Lett. **109**, 243904 (2012)

Flux exclusion superconducting quantum metamaterial: towards quantum-level switching

V. Savinov, *et al.*

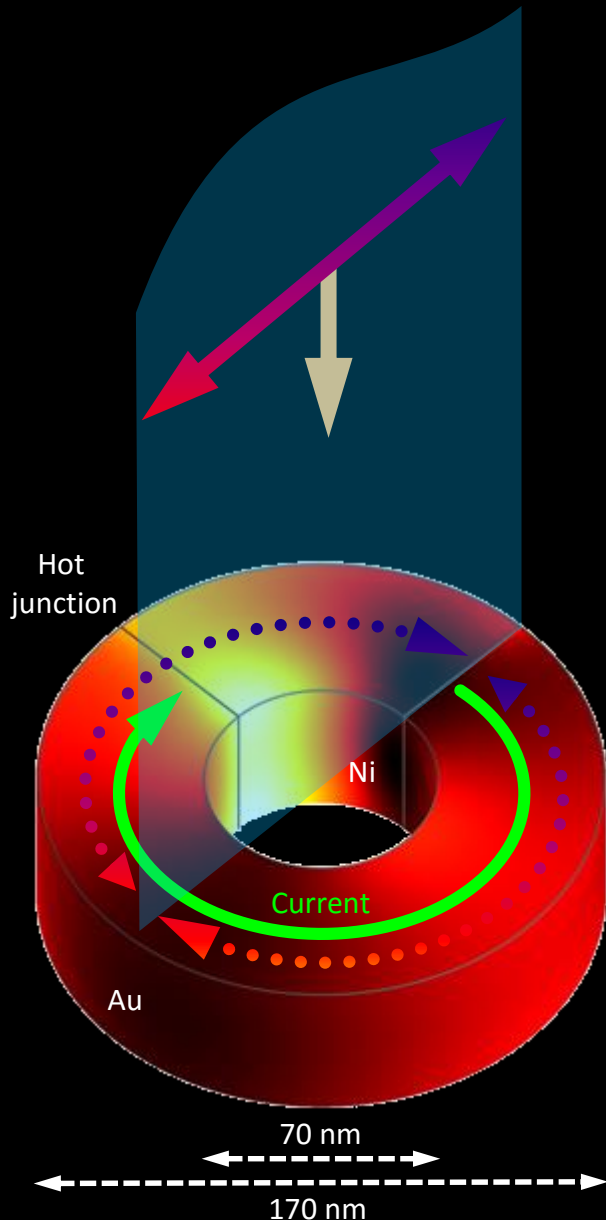
Sci. Rep. **2**, 450 (2012)

Temperature control of Fano resonances and transmission in superconducting metamaterials

V. A. Fedotov, *et al.*

Opt. Express **18**, 9015 (2010)

Magnetic Field & Metamaterials



Reconfiguring photonic metamaterials with currents and magnetic fields

J. Valente, *et al.*

Appl. Phys. Lett. **106**, 111905 (2015)

Giant magnetic modulation of a planar, hybrid metamolecule resonance

S. A. Gregory, *et al.*

New J. Phys. **16**, 063002 (2014)

Magnetic control of a meta-molecule

G. B. G. Stenning, *et al.*

Opt. Express **21**, 1456 (2013)

Optical generation of intense ultrashort magnetic pulses at the nanoscale

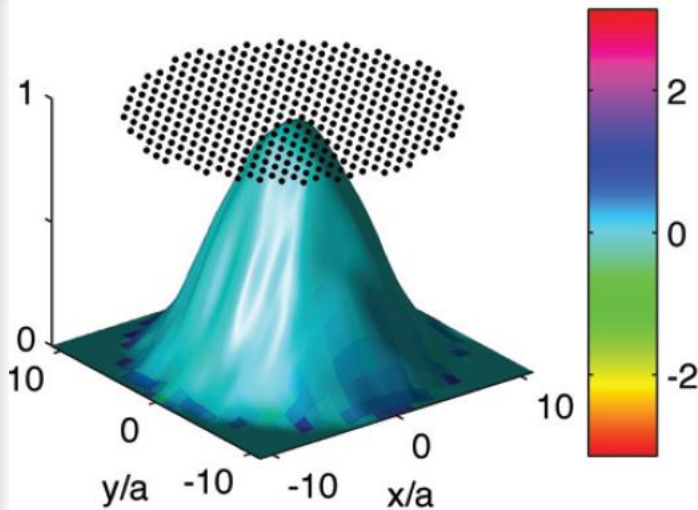
A. Tsiatmas, *et al.*

New J. Phys. **15**, 113035 (2013)

Quantum Theory of Metamaterials

Theoretical formalism for collective electromagnetic response of discrete metamaterial systems

S. D. Jenkins and J. Ruostekoski
Phys. Rev. B **86**, 085116 (2012)



Cooperative resonance linewidth narrowing in a planar metamaterial

S. D. Jenkins and J. Ruostekoski
New J. Phys. **14**, 103003 (2012)

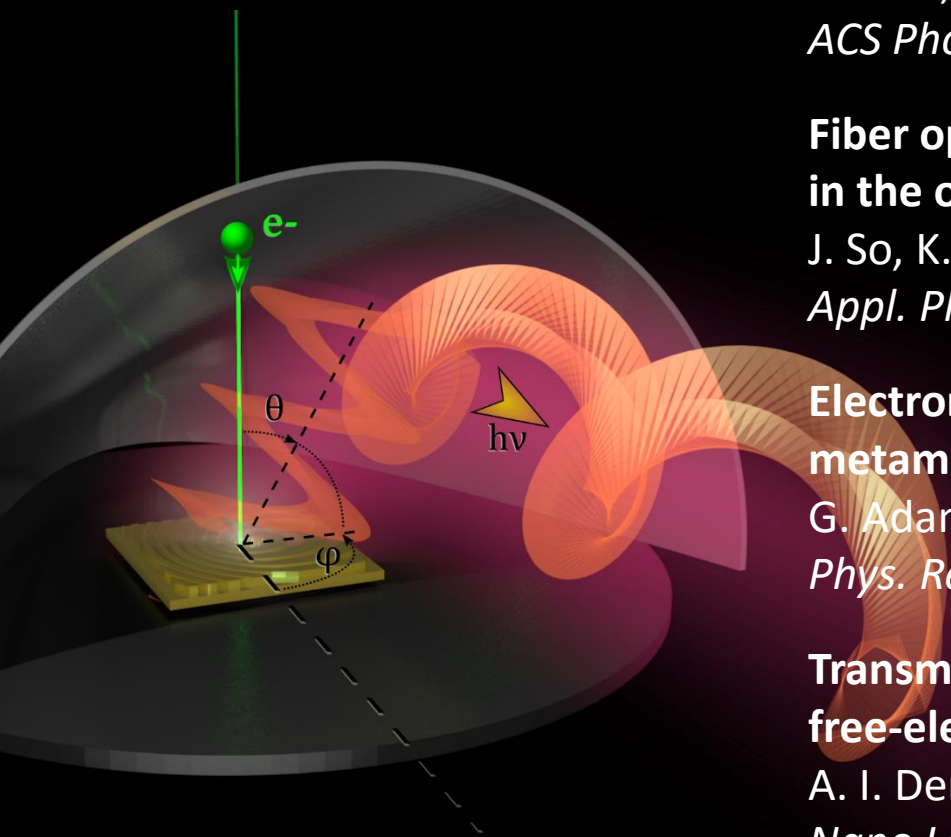
Resonance linewidth and inhomogeneous broadening in a metamaterial array

S. D. Jenkins and J. Ruostekoski
Phys. Rev. B **86**, 205128 (2012)

Controlled manipulation of light by cooperative response of atoms in an optical lattice

S. D. Jenkins and J. Ruostekoski
Phys. Rev. A **86**, 031602(R) (2012)

Free-electrons and Metamaterials



Amplification of the Evanescent Field of Free Electrons

J. K. So, K. F. MacDonald, and N. I. Zheludev
ACS Photonics **2**, 1236 (2015)

Fiber optic probe of free electron evanescent fields in the optical frequency range

J. So, K. F. MacDonald, and N. I. Zheludev
Appl. Phys. Lett. **104**, 201101 (2014)

Electron-beam-driven collective-mode metamaterial light source

G. Adamo, *et al.*
Phys. Rev. Lett. **109**, 217401 (2012)

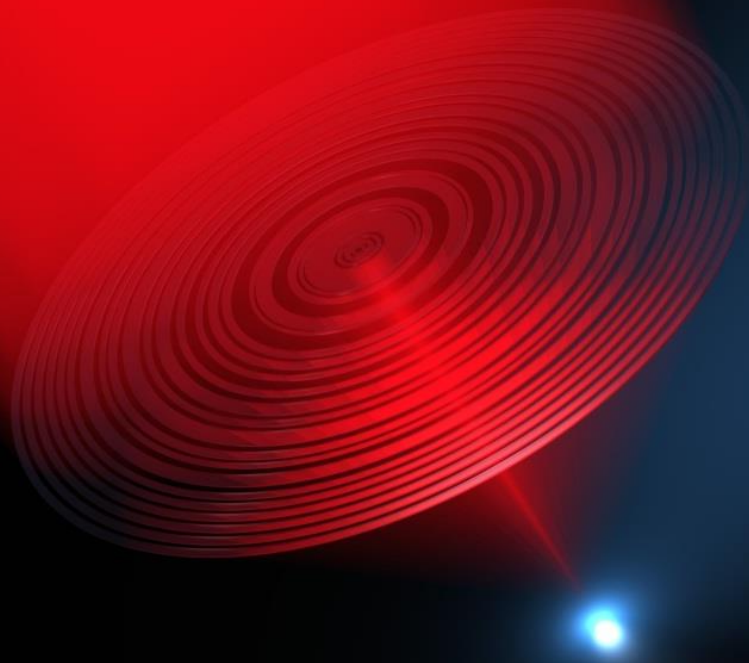
Transmitting Hertzian optical nanoantenna with free-electron feed

A. I. Denisyuk, *et al.*
Nano Lett. **10**, 3250 (2010)

Tuneable electron-beam-driven nanoscale light source

G. Adamo, *et al.*
J. Opt. **12**, 024012 (2010)

Localization of Light and Metamaterials



Sub-wavelength focusing meta-lens

T. Roy, E. T. F. Rogers, and N. I. Zheludev
Opt. Express **21**, 7577 (2013)

Super-oscillatory optical needle

E. T. F. Rogers, *et al.*
Appl. Phys. Lett. **102**, 031108 (2013)

“Digitally” addressable focusing of light into a subwavelength hot spot

T. S. Kao, *et al.*
Nano Lett. **12**, 2728 (2012)

Coherent control of nanoscale light localization in metamaterial: creating and positioning a sub-wavelength energy hot-spot

T. S. Kao, *et al.*
Phys. Rev. Lett. **106**, 085501 (2011)

Localization of electromagnetic fields in disordered metamaterials

S. Savo, *et al.*
Phys. Rev. B **85**, 121104(R) (2012)

A super-oscillatory lens optical microscope for subwavelength imaging

E. T. F. Rogers, *et al.*
Nature Mater. **11**, 432 (2012)

Chiral Metamaterials

Chiral mirrors

E. Plum and N. I. Zheludev

Appl. Phys. Lett. **106**, 221901 (2015)

Giant nonlinear optical activity in a plasmonic metamaterial

M. Ren, E. Plum, J. Xu and N. I. Zheludev

Nat. Commun. **3**, 833 (2012)

Metamaterial polarization spectral filter: isolated transmission line at any prescribed wavelength

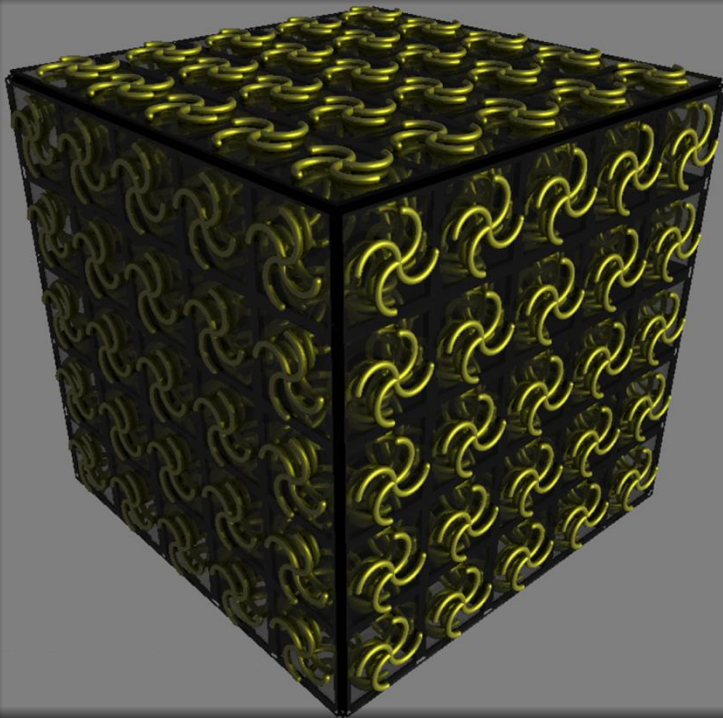
N. I. Zheludev, E. Plum, V. A. Fedotov

Appl. Phys. Lett. **99**, 171915 (2011)

Electromagnetic wave analogue of an electronic diode

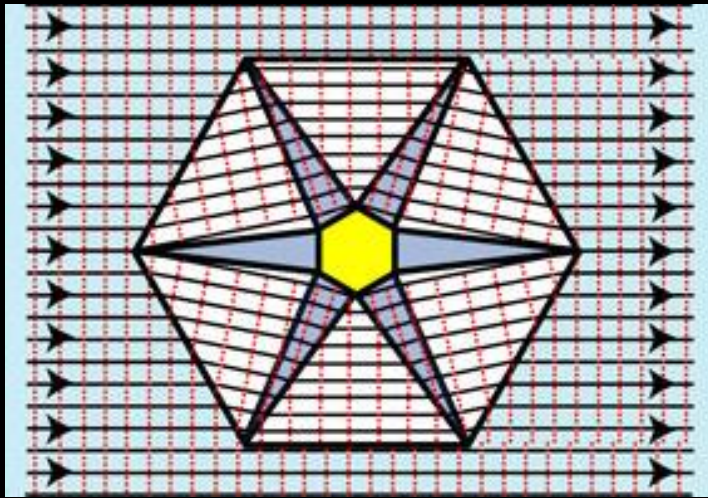
I. V. Shadrivov, *et al.*

New J. Phys. **13**, 033025 (2011)



Cloaking

(Singapore collaboration)



Wavevector selective metasurfaces and tunnel vision filters

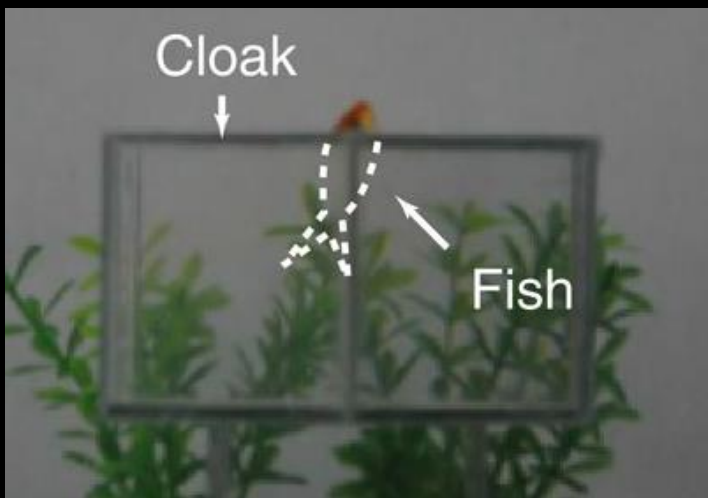
V. A. Fedotov, J. Wallauer, M. Walther, M. Perino, N. Papasimakis, N. I. Zheludev
Nature: Light Sci. Appl. **4**, e306 (2015)

Ray-optics cloaking devices for large objects in incoherent natural light

H. Chen, *et al.*
Nature Commun. **4**, 2652 (2013)

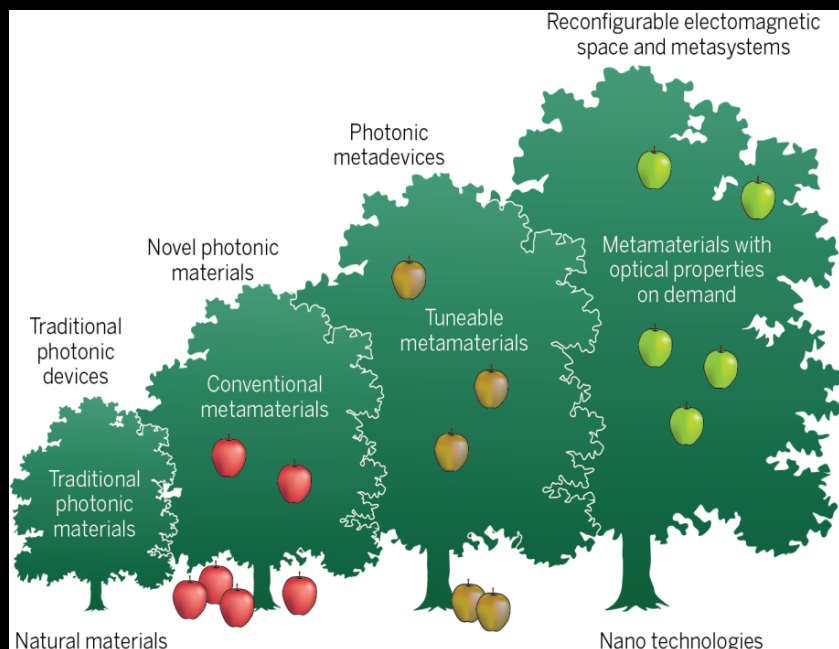
Optofluidic waveguide as a transformation optics device for lightwave bending and manipulation

Y. Yang, *et al.*
Nature Communications **3**, 651 (2012)



[Video link](#)

Strategic Papers on Metamaterials



Roadmap on optical metamaterials

A. M. Urbas, *et al.*

Journal of Optics (in press 2016)

Obtaining optical properties on demand

N. I. Zheludev

Science **348**, 973 (2015)

From metamaterials to metadevices

N. I. Zheludev and Y. S. Kivshar

Nature Mater. **11**, 917 (2012)

The Fano resonance in plasmonic nanostructures and metamaterials

B. Luk'yanchuk, N. I. Zheludev, S. A. Maier,
N. J. Halas, P. Nordlander, H. Giessen

Nature Mater. **9**, 707 (2010)

A roadmap for metamaterials

N. I. Zheludev

OPN **22**, 30 (2011)

Active plasmonics: current status

K. F. MacDonald and N. I. Zheludev

Laser Photon. Rev. **4**, 562 (2010)

The road ahead for metamaterials

N.I. Zheludev

Science **328**, 582 (2010)

EPSRC Programme 2015-2021: The Physics and Technology of Photonic Metadevices and Metasystems

- Optical Properties on Demand
- Telecoms Metadevices & Metasystems
- New Functional Materials for Metamaterials

UNIVERSITY OF
Southampton



Co-Investigators

Prof. N. I. Zheludev [PI]
Prof. D. J. Richardson
Dr. K. F. MacDonald

Prof. B. Hayden
Prof. O. Muskens
Dr. E. Plum

Prof. D. Faccio

Industrial Partners

Defence Science & Tech. Lab



Iluka **ilika**

BAE Systems

BAE SYSTEMS

Oclaro Technology UK



International Academic Partners

Nanyang Technological University



National Taiwan University



Other Collaborators & Sponsors



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