Infrared Phase-Change Metadevices

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## Acknowledgements

**PhD students from Exeter’s CDT in Metamaterials**

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<tr>
<th>Santiago García-Cuevas Carrillo</th>
<th>Carlota Ruiz De Galarreta</th>
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<td><img src="image" alt="Liam Trimby" /></td>
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**Exeter staff**

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<th>Dr Jacopo Bertolloti</th>
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<td><img src="image" alt="Dr Arseny Alexeev" /></td>
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**Collaborators from Bristol**

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<th>Prof Martin Cryan</th>
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**Collaborators from Southampton**

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<th>Prof Dan Hewak</th>
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**Collaborators from Oxford**

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<th>Prof Harish Bhaskaran</th>
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QinetiQ

Dyson
What are phase-change materials?
Chalcogenide phase-change materials

What are phase-change materials?

Amorphous ↔ Crystalline

- Fast transition time (ns)
- High electro-optical contrast
- Non-volatile

Optical changes on phase-switching

Electrical changes on phase-switching
Chalcogenides – alloys of chalcogens with other elements
Chalcogenide phase-change alloys – e.g. \( \text{Ge}_2\text{Sb}_2\text{Te}_5 \) – phase-change materials
Transition-metal dichalcogenides – e.g. MoS\(_2\) – 2D materials with bandgap
Existing uses of phase-change materials

Re-writable optical discs
- DVD-RW, DVD+RW, DVD-RAM
- Blu-ray RE (100 Gbyte)

Non-volatile electrical memory
- High-end SSD replacement
- Intel-Micron joint venture
What are metadevices?
Phase-change **metadevices**

Combine *phase-change materials* and *optical metasurfaces* to deliver new photonics functionality.

**Conventional metasurfaces** typically have patterned metal top layer, metal ground plane and dielectric spacer.

Optical response tailored by exploiting *plasmonic resonances*.

Response is fixed by design (shapes, sizes, thicknesses, materials).

Example – **broadband solar absorber**

Phase-change meta-devices

Phase-change meta-devices replace the (passive) dielectric with a phase-change layer - acts as switchable dielectric

Optical response different for phase-change layer in amorphous and crystalline phases

Switch between two phases optically or electrically

Devices with tunable, switchable, re-configurable optical response

- Tuned, re-configurable absorbers (modulators)
- Beam steering with no moving parts
- Tunable multispectral filters
- Re-configurable lenses
- Spatial light modulators
- Moving holograms

See: S G-C Carrillo et al., Optics Express 24, 13563 (2016)
C Ruiz de Galarreta et al., Adv Funct Mater (submitted)
Examples of phase-change IR metadevices
Phase-change **meta-absorbers/modulators**

Example – a *near-infrared* meta-absorber/modulator

Device optimised for optimum modulation depth at 1550 nm by

- varying width and spacing of top metal stripes and
- varying thickness of GST and ITO layers

MD = ratio of device reflectance for GST layer in *crystal/amorphous* phases

See: S G-C Carrillo et al., *Optics Express* 24, 13563 (2016)
Phase-change *meta-absorbers/modulators*

*Simulated device reflectance spectrum* (Au metal layers)

Absorption (1550 nm) \(\sim\) 99%
MD (1550 nm) \(\sim\) 76%
Plasmon-induced electric and magnetic dipoles

Electric dipole
(and image)

Magnetic dipole

Reflectance (a.u.)

1550 nm

Frequency [Hz]
Phase-change meta-absorbers/modulators

**Experimental devices** (Al metal layers)

- Experimental reflectance spectra
  - starting phase amorphous
  - crystallised by scanned 405 nm laser
  - good agreement between simulated and actual spectra
Phase-change **meta-absorbers/modulators**

*Ex-situ optical switching* is relatively easy

*In-situ electrical switching* more attractive for real-world devices

*See poster by Santiago Garcia-Cuevas Carrillo*  
- Phase-change meta-devices for near-infrared absorbers & modulators
Phase-change *beam-steering meta-devices*

Here we *control the optical phase of the reflected wave* (cf. control of amplitude in absorber devices)

**Generalized Snell’s Law**

\[
\sin(\alpha_r) = \sin(\alpha_i) + \frac{\Delta \phi \lambda_0}{2\pi d}
\]
Phase-change beam-steering metadevices

Unit cell design

- Design wavelength, $\lambda = 1550\text{nm}$

Super cell design

See: C Ruiz de Galarreta et al., Adv Funct Mater (submitted)
Beam-steering meta-devices: Device Fabrication

1) Clean SiO2/Si Substrate

2) Magnetron sputtering (Aluminum, ITO, GST, ITO)

3) PMMA spin coating

4) E-beam lithography

5) Magnetron sputtering (Aluminum)

6) PMMA lift off
Beam-steering metadevices: Device Fabrication

See: C Ruiz de Galarreta et al., Adv Funct Mater (submitted)
Beam-steering metadevices: \textit{Device characterisation}

Measurements carried out at University of Bristol

$\lambda = 1550 \text{ nm}$
Phase-change **beam-steering metadevices**

Possible applications

- LIDAR (autonomous vehicles, robotics)
- Beam coupling (communications)
- Modulation (cf. AO, LCD modulators)
- Camouflage (deflection incoming beams)

*See poster by Carlota Ruiz de Galarreta*
- Beam steering and beam shaping phase-change metasurfaces working in the near infrared
Multispectral imaging phase-change metadevices

See poster by Liam Trimby
- Multispectral Imaging using Phase-Change Meta-Filters
**Dielectric phase-change metadevices**

All devices so far have exploited *plasmonic resonances in metals*

Plasmonic losses can be high

Is there an alternative, low-loss approach?

Yes – *dielectric phase-change metadevices*
Dielectric phase-change metadevices

Modulation of reflection in 1350-1650 nm range.

Efficiencies can be very high (80-90%)

See poster by Arseny Alexeev

- Tunable dielectric metadevices enabled by phase-change materials
Summary

Phase-change materials used successfully for optical & electrical memories

Optical metasurfaces used successfully to deliver flat thin-film optics

By combining phase-change materials and metasurfaces, can deliver a wide range of new and improved optical/photonic functionality

Possible devices include:

• Tunable/reconfigurable absorbers and modulators
• Beam steerers and beam transformers
• Spatial light modulators
• Reconfigurable lenses
• Non-volatile and holographic displays

Application areas include:

• Imaging and sensing
• Autonomous vehicles and robotics
• Communications
• Security and defence
• Bio-medical instrumentation

Can work over a wide range of wavelengths – visible, NIR, MIR