Recent development in specialty Multi-material fibres

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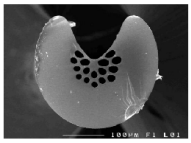
SwissPhotonics June, 26th 2014

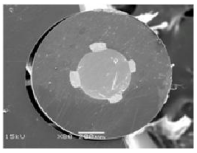
OVERVIEW

How to integrate increasingly complex functionalities inside optical fibres ?

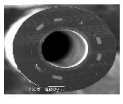
I. Innovative Fibre structures and Materials

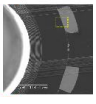


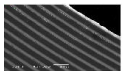
II. Multi-material fibre paradigm



III. Example of multi-material fibre devices

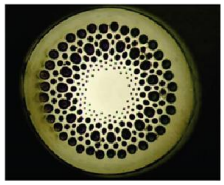




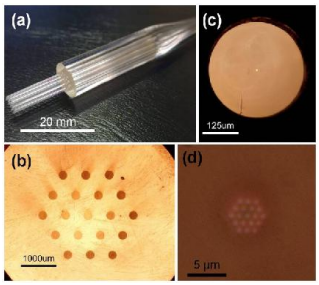


Innovative structures

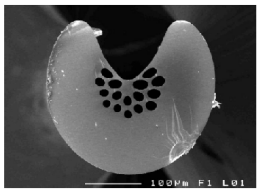
- Increasingly complex structures bring novel functionalities
- Extremely mature fabrication process



PC Fibre



Multicore fibre – Argyros 2011



Bureau et. al. (Rennes)

- Optical manipulation (polarization, dispersion…)
- Sensing
- Laser machining
- Health care

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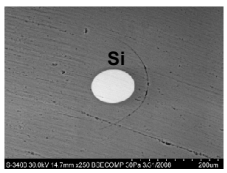
Innovative Materials

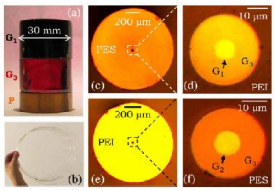
- Novel integrated mateirals bring novel opportunities

Silicon in Silica fiber



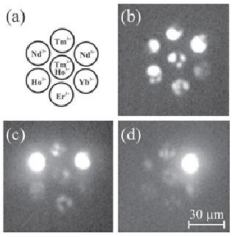
Ballato, Clemson Univesity, USA.

Nonlinear chalcogenide glasses



Abourady et al., CREAOL, Florida 2013

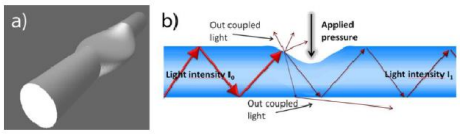
Multiple Fluorescent cores



V. Romano et al., Int. J. of Mod. Phy. B 28 1442010 (2014)

Bern Unniversity

Stretchable polymer optical fiber (extrusion)



Scherer et al, EMPA 2012

- Nonlinear optical effects
- Fluorescent based devices
- Fiber lasers
- Sensors…

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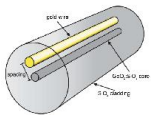
Post-drawing processing

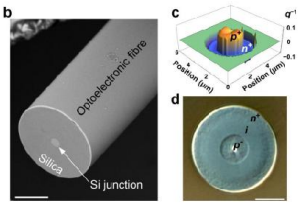
- Fiber is used as a template to integrate materials to go beyond the realm of optics and photonics

Pumping metal inside hollow channels

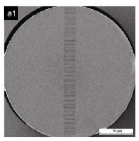


Prof. Russel (Max Planck Institute)
Prof. Schmidt (Jena University)

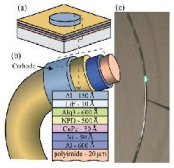
High pressure CVD to integrate semiconducting materials and junctions



Fabricating structure on fiber cross-section and side

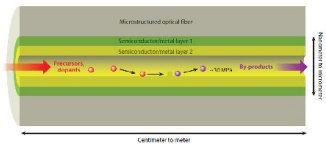


Kostovski, Adv Mat 2014



Shtein, Adv Mat 2007

Badding, Penn State University, USA
Science (2006), Nature Photonics (2012)



- **Integrated optoelectronic, sensing, monitoring, smart network…**
- **Towards integrated multi-functional optical fibres ?**
- **Scalability ? Distributed functions ? Versatility in structures and functions ?**

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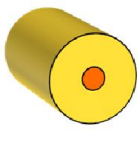
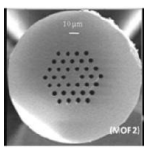
Multi-material Fiber paradigm

Engineering novel 1D nanostructured devices

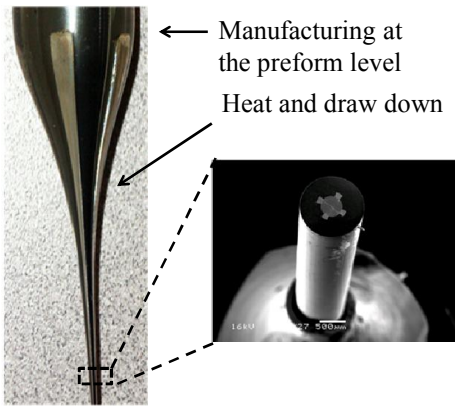
Conventional and specialty Optical fibers





- **Glass fibers exhibit key features:**
  - **Transparency window**
  - **Non-linear properties**
  - **Photosensitivity**
  - **Extended interaction length**
- **Fabrication approach is extremely advanced:**
  - **Complex structures**
  - **Highly uniform, flexible fibers**
- **Extended length is also extended surface !**
- **Can we exploit this fabrication technique and other properties of glasses ?**

Materials | **Structure** | **Length scale**



← Manufacturing at the preform level

Heat and draw down

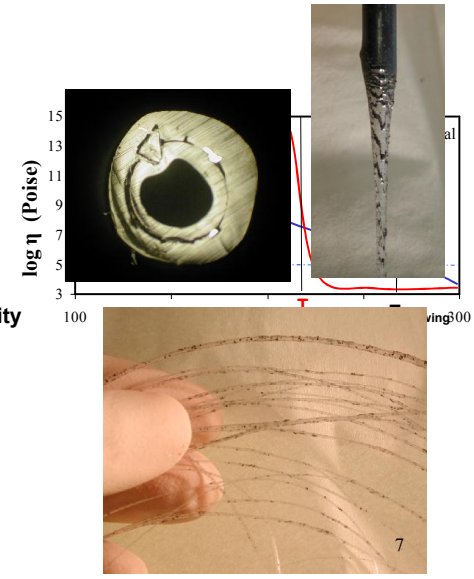
→ Extended length of functional optoelectronic fibers

FABRICATION CHALLENGES

Materials with different optic and optoelectronic properties also often have different thermo-mechanical properties

Thermo-mechanical properties

- Glassy materials: Continuous derivative dη/dT with respect to temperature
- Upper bound viscosity (η) at a common temperature: less 10^7 Poise (ΔT_g < 30C)
- Resistant to crystallization (T_x-T_g>100C)
- Or materials can flow in a very low viscosity liquid state



Fabrication and Processing

- Careful preform machining
- Finding the right drawing parameters

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MATERIALS SELECTION

HIGH-Tg TERMOPLASTICS

- Electrical Insulators
- PES, PEI
- Amorphous thermoplastics
- Glassy transition temperature: 150-240 °C
- Refractive index @1.5 microns: 1.6
- Availability: Thin films (8-150 microns)

METALS

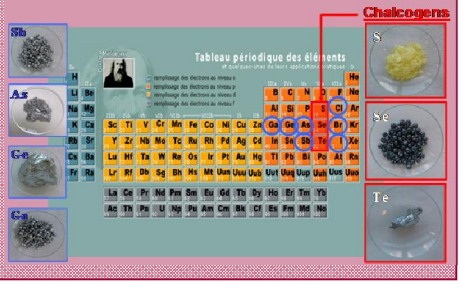
In, Sn, Bi(43%)-Sn(57%)

- Metals
- Crystalline Materials
- Melting Temperature: 140-232 °C
- T_m has to be lower than the drawing temperature
- Good wetting of glass and polymer
- Use of Flux to prevent oxidization
- Low viscosity at drawing Temperature

AMORPHOUS SEMICONDUCTORS

As, Se, S, Ge, Te, Si, Sn

- Amorphous semiconductors (p-type)
- Glass transition temperature: 160-210 °C
- Refractive index @1.5 microns: 2.4-3.4
- High electrical conductivity
- CTE for As2Se3: 25*10^-6/C
- Photoconductivity



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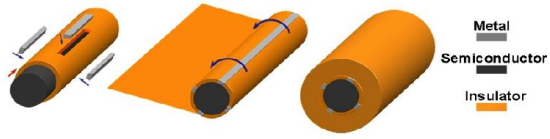
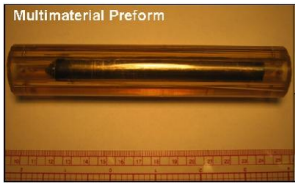
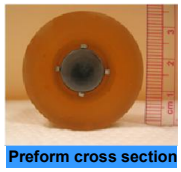
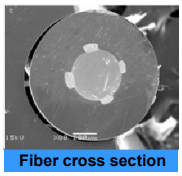
The first Metal-Insulator-Semiconductor fiber





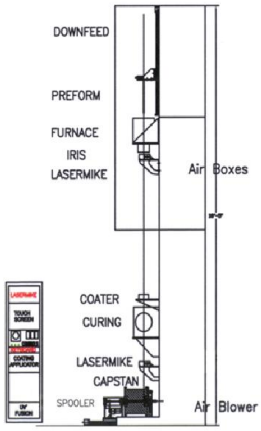


Preform cross section



Fiber cross section

Draw-tower



The thermal drawing process inherently generates surface area !

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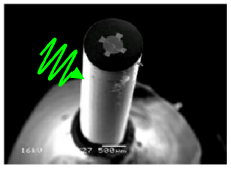
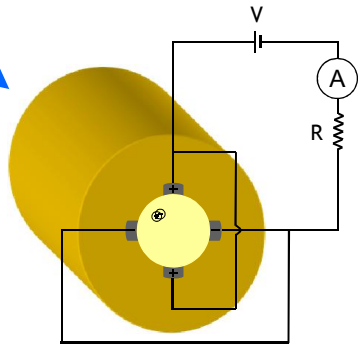
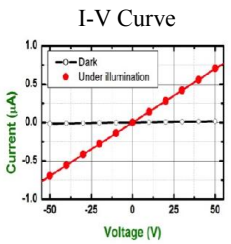
M. Bayindir, F. Sorin, et al *Nature* 431, 826 (2004)

OPTOELECRONIC FIBER SENSORS

We have already made a photoconductor



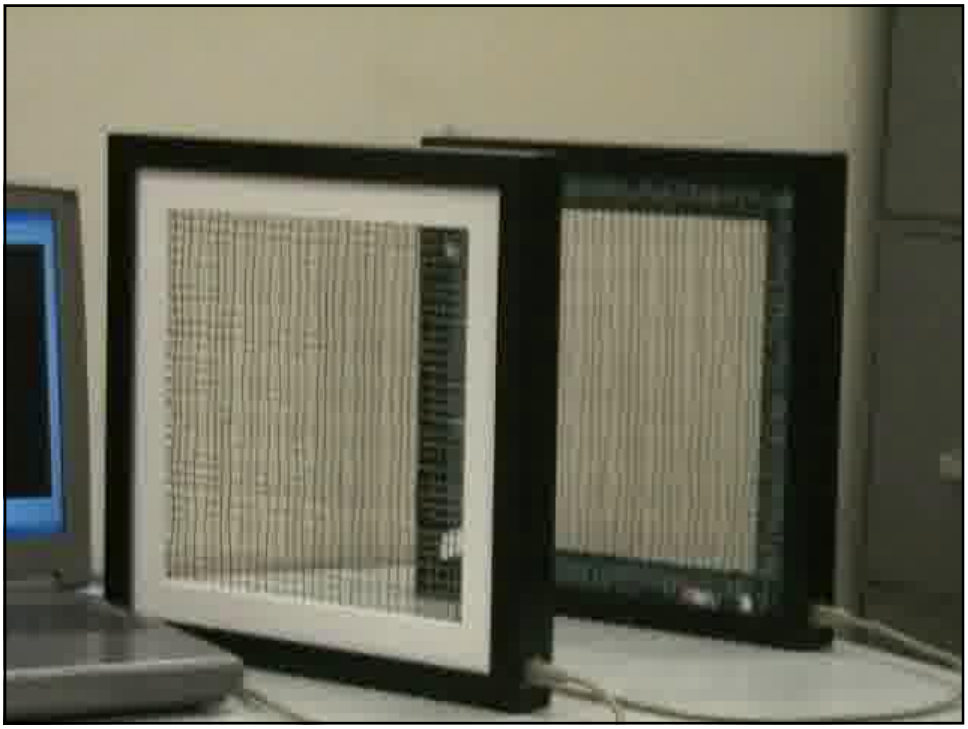




Extremely large area flexible optoelectronic devices

Can we integrate increasingly complex and innovative device structures ?

M. Bayindir, F. Sorin, A.F. Abouraddy et al *Nature* 431, 826 (2004)



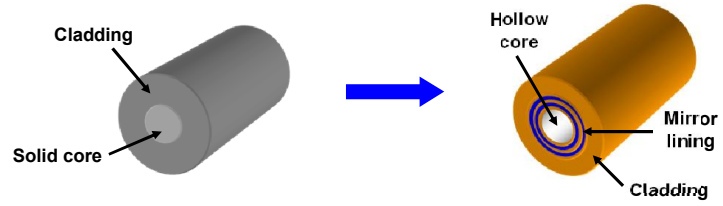
Combining optical and electronic functionalities

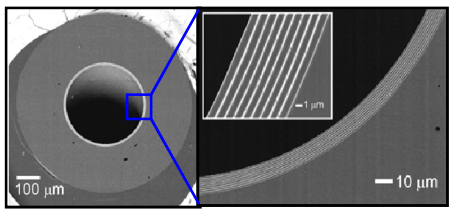
FIMAP

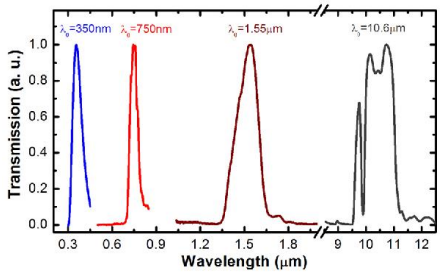
PBG fibers address the intrinsic limitations, *non-linear effects, absorption losses and dispersion*, of conventional optical fiber.

Conventional optical fiber guides light through solid core by total internal reflection

Omnidirectional mirror lining can allow light guidance through air







B. Temelkuran, *Nature* 420, pp 650–653 (2002).

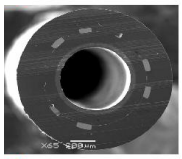
Fibers for non-invasive surgeries

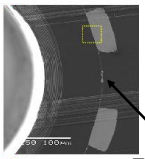
- Self monitored optical fibers -

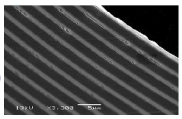
Omniguide PBG fibers for non-invasive surgeries:

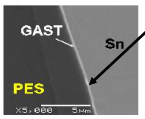
- **CO2 laser line highly absorbed in water**
- **Flexible scalpel to remove unwanted tissue**

- **Add a thermal sensor that surrounds the PBG structure.**
- **Defects characterized by local heating detected at any point along the fiber length**





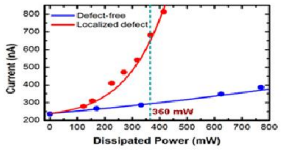


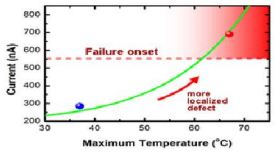


Thermal Sensor

$As_{40}Se_{60}$

$Ge_{17}As_{23}Se_{14}Te_{46}$

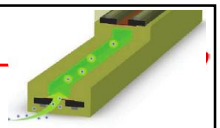




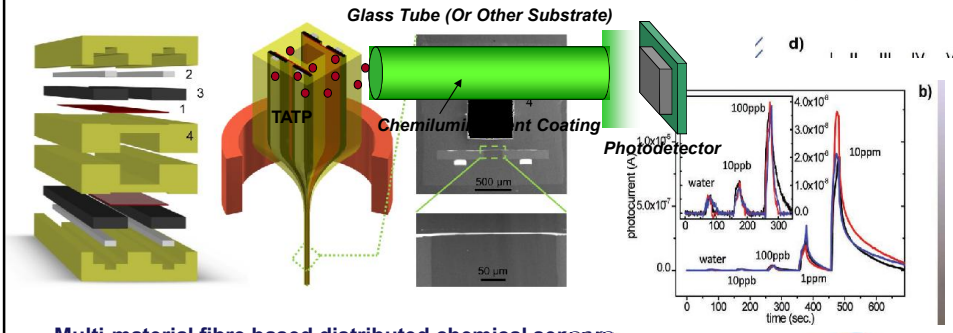
F. Sorin et al., Patents Licensed by Omniguide Inc.

All in-fiber chemical sensing

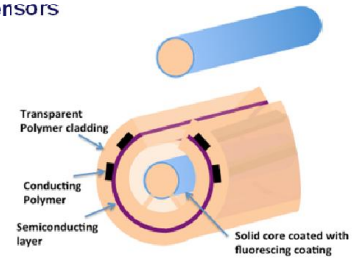
A new detection paradigm



Fiber for chemical sensing: **chemoluminescent material**



- **Multi-material fibre based distributed chemical sensors**
  - **Optical based distributed sensors are limited**
  - **An innovative design of a photonic fiber device**
  - **Noise transferred in the electronic domain:**
    - **Optical losses go as $10^{-\alpha L/10}$**
    - **Electronic noise goes as $\sqrt{L}$.**



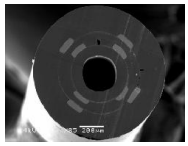
Gumenik, .., Sorin, et al, Advanced Materials 24, 6005 (2012)

Sorin et. al., Fiber Society meeting, Clemson, US (2013)

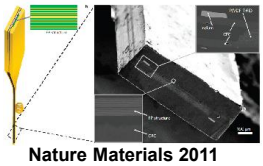
Novel photonic devices and architectures

- Developing new materials, new structures and new functionalities

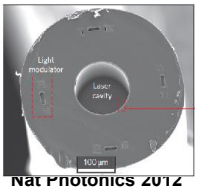
Heat sensors
Chemical sensors
Functional polymers
Fiber capacitors
…



NanoLetters 2009

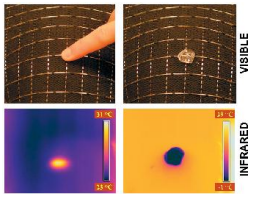


Nature Materials 2011



Nat Photonics 2012

- Fiber devices and fiber assemblies



- Health care
- Smart fabrics
- Sensing and monitoring
- Laser machining
- Nonlinear optics…

- Interfacing multi-material and multi-functional fibres with optical and electrical networks ?
- Great opportunities in small network
- Opportunities in 1D networks: fiber to home sensing and monitoring, amplification….

centimeter

meter

Tens of meters

kilometer

EMERGING SCIENTIFIC AND TECHNOLOGY PLATFORM

Energy Harvesting
Storage and saving

Sensing - monitoring

Applications

Innovative Healthcare systems
Smart Textiles

Specialty Optical Fibers

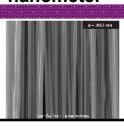
Large area and flexible systems

2D innovative photonic structures
Multi-material Fibers

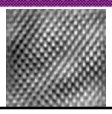
Materials/Interfaces, Processing, Geometry and Length Scale

micrometer

nanometer



Angstrom



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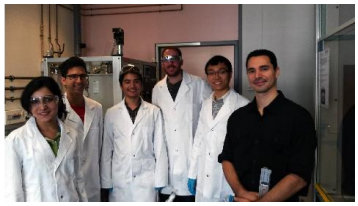

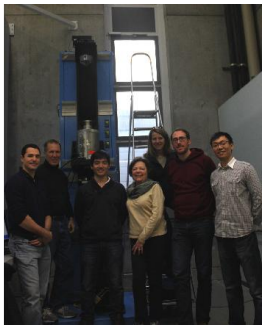

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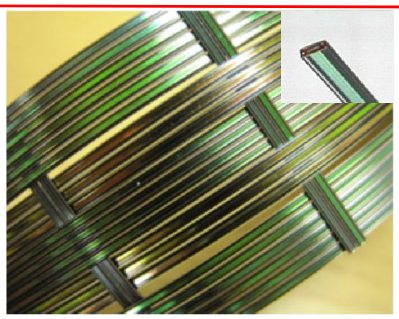

THANK YOU

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