Photon 411:
Enabling Information at the Speed of Light

Joel M. Hales

School of Chemistry and Biochemistry, Center for Organic Photonic and Electronics,
Georgia Institute of Technology

Blended Research @ the Library
Multidisciplinary Perspectives for Everyone

Manipulating Light
From Design to Application

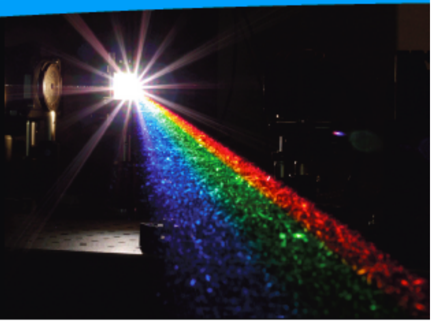
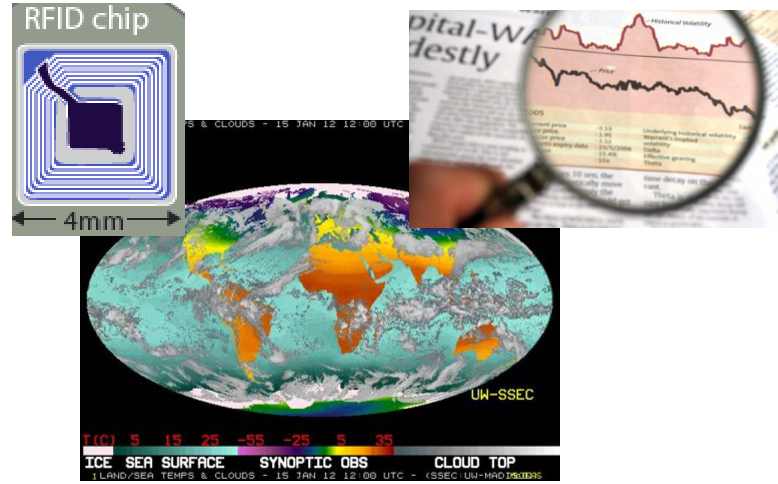


Photo courtesy Peeter Piksarv
http://commons.wikimedia.org/wiki/File:Valge_valguse_spekter.jpg

Information-Intensive Areas

Entertainment

Data Gathering



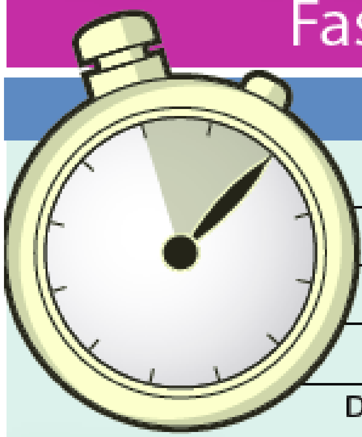
Remote Learning

Telesurgery

Growing Information Needs

From International Telecommunications Union

Faster web access



Download	256kbp/s	2Mbp/s	100Mbp/s
Google home page	5s	0.6s	0.64s
Music track	2m36s	2s	0.40s
Video clip	10m5s	1m20s	1.60s
CD/low-quality movie	6h	47m	55s
DVD/high-quality movie	34h17m	4h29m	5m

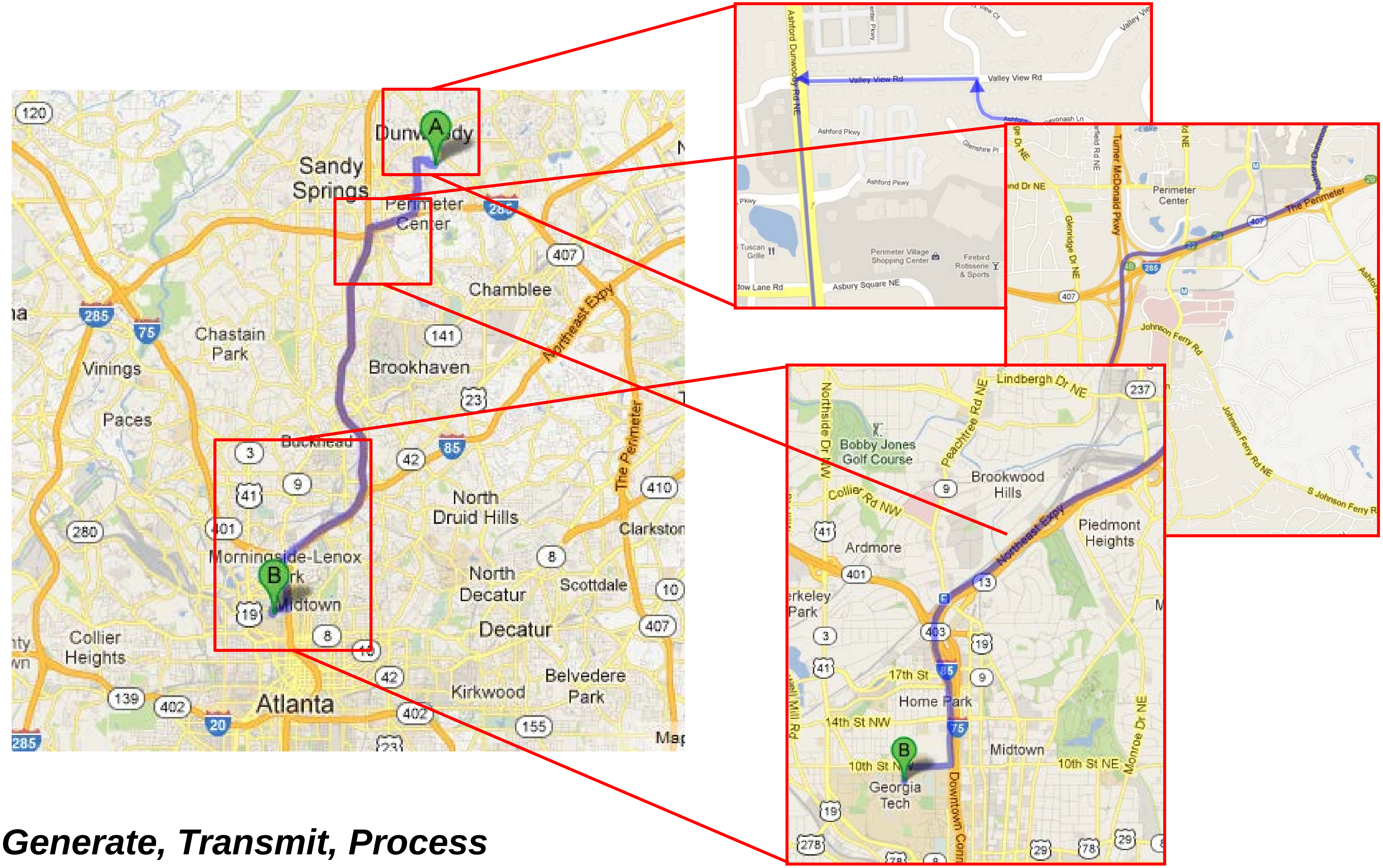
- ✓ By end of 2011 2.3 billion people were online
- ✓ Total international Internet bandwidth increased 7× over last five years
- ✓ Mobile and wired broadband growing

What needs to occur during this information transfer?

- ➢ **Generation, Transmission, and Processing of information**

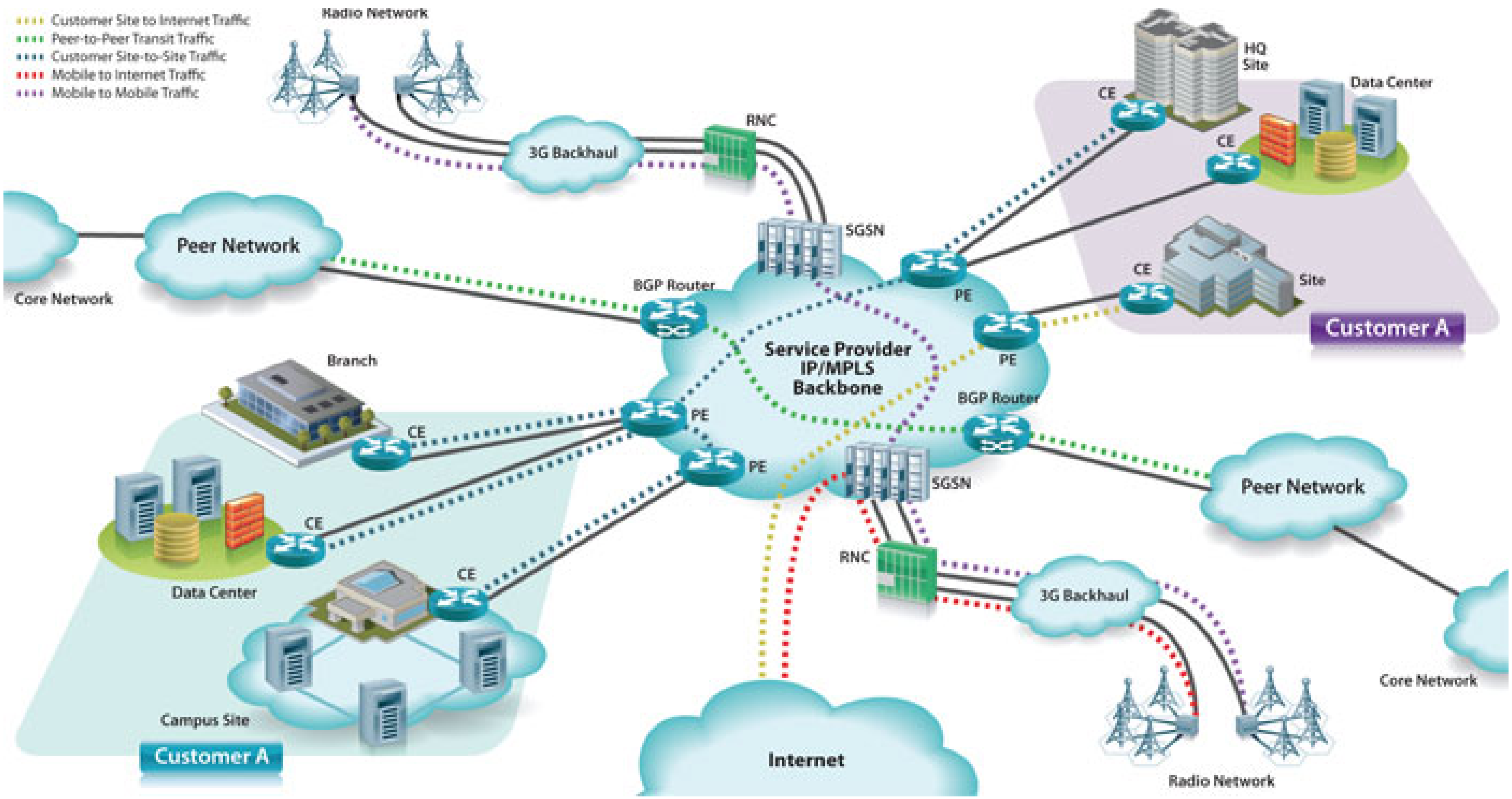
Who Loves Traffic?

Georgia Tech



Generate, Transmit, Process

Network Information Traffic



Generate, Transmit, Process

Why Photonics Over Electronics?

Photonics *includes generation, transmission and processing of light*

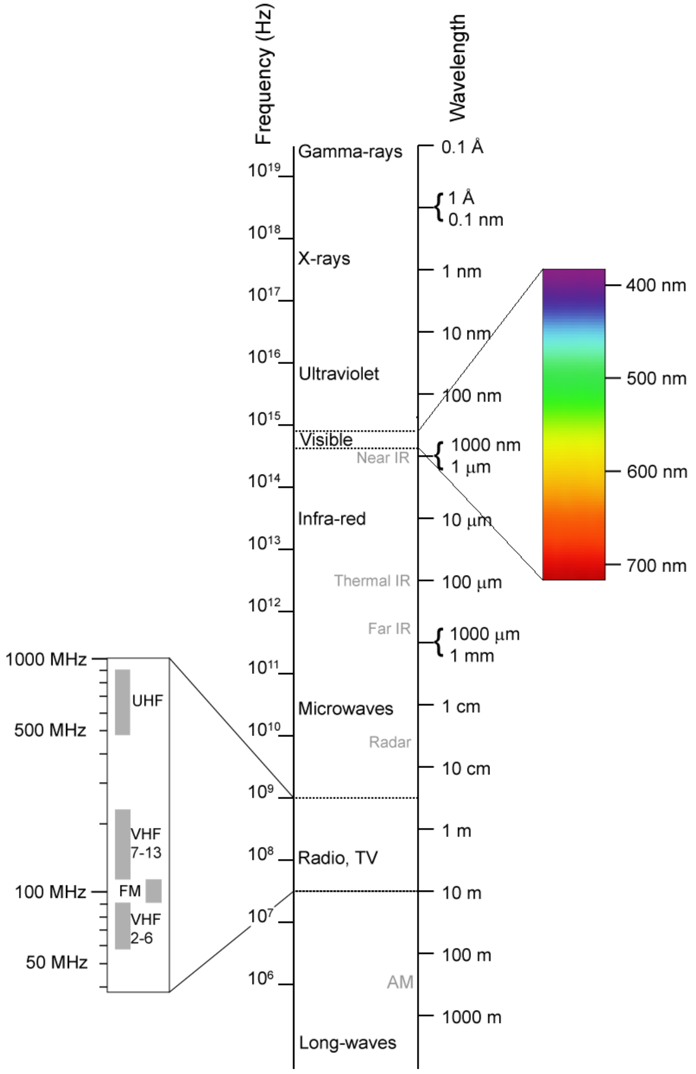
- Bandwidth of audio signals: ~ 20 kHz
- Bandwidth of analog video: ~ 7 MHz
- Digital and HD video can be greater

Benefits:

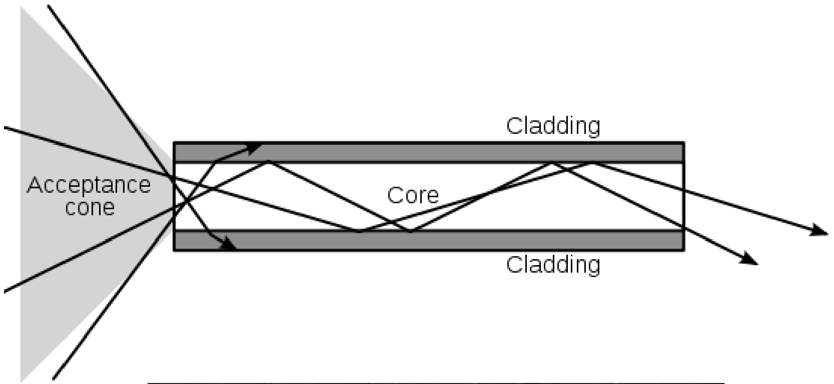
1. *Bandwidth* – capacity for carrying information
2. *Minimal interference* – no EMI, low cross-talk
3. *Low loss* – for long distances
4. *Fast* – for processing or routing

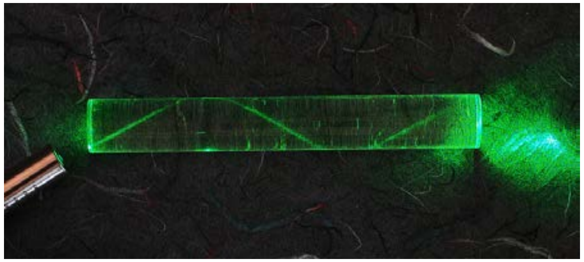
Drawbacks:

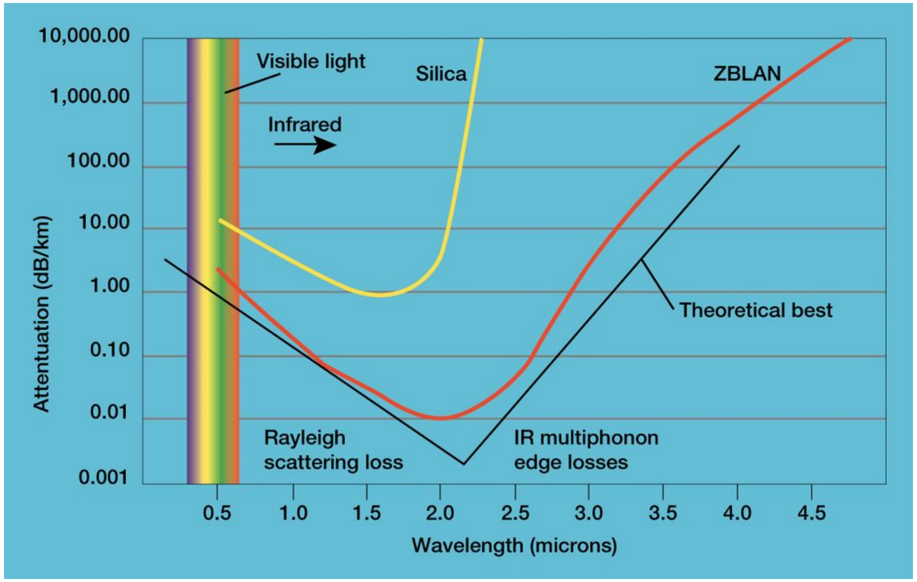
1. *Cost, cost, cost* – infrastructure in place
2. *Processing* – electronics more mature



Generation & Transmission: Fibers



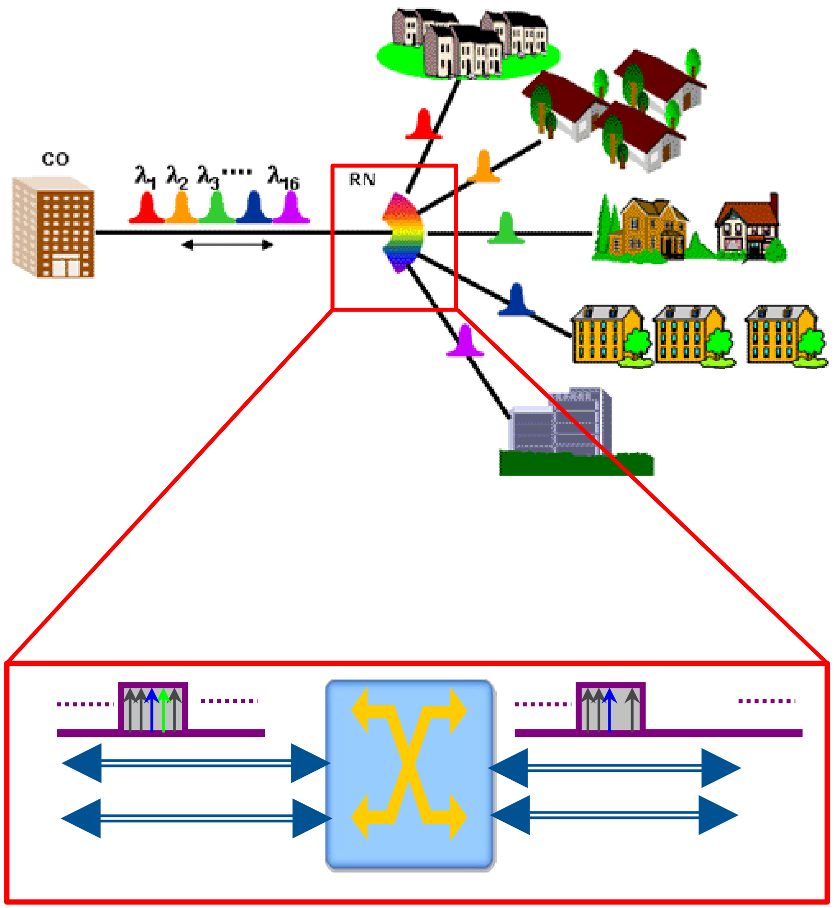




<u>Key breakthroughs:</u>

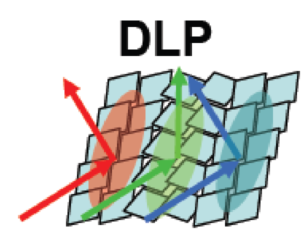
- ✓ Semiconductor lasers permit generation of information
- ✓ Low loss fibers enable transmission over long distances
- ✓ Amplification allows for even longer distances

Processing: Routing & Switching

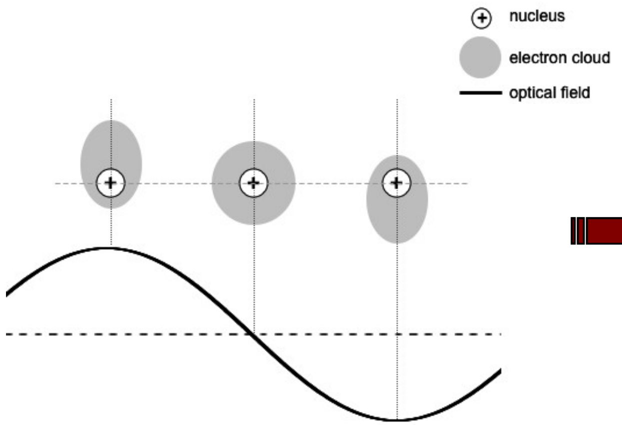


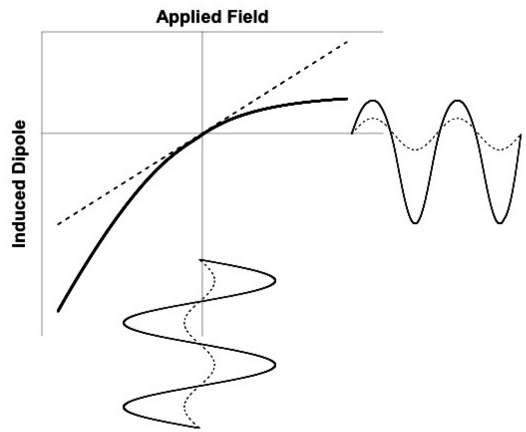
1. **Electronic switching – OEO:**
   - Conversion to take advantage of mature switching technology
   - Switching time ~ microseconds
   - Power consumption issues

2. **"All-optical switching"**
   - No conversion to electrical signals needed
   - Switching time slow ~ 10's milliseconds
   - Larger footprint



Nonlinear Optics

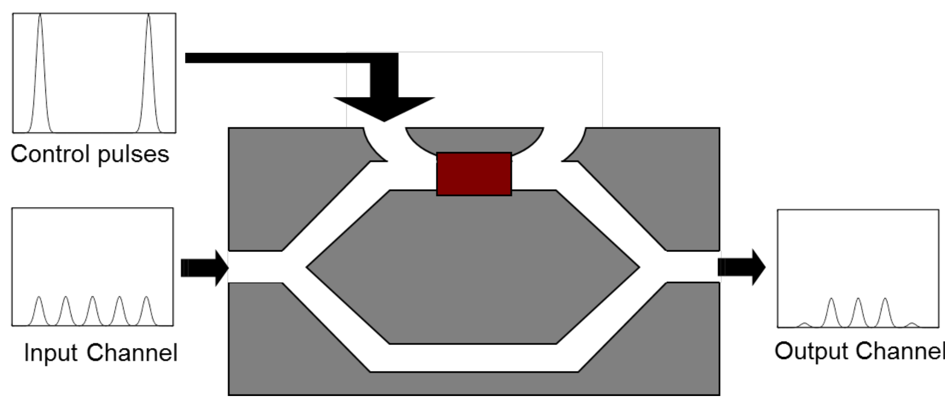




$$n = n_0 + n_2 I$$
$$\alpha = \alpha_0 + \beta I$$

The material's optical properties will be modified by the incident light intensity.

The modified optical properties will, in turn, cause changes in the incident light.

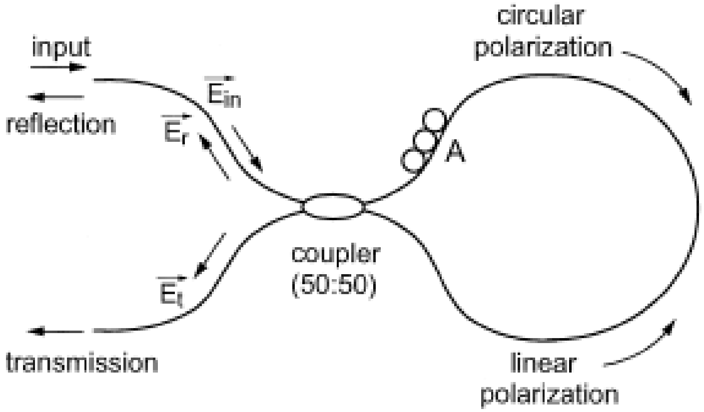


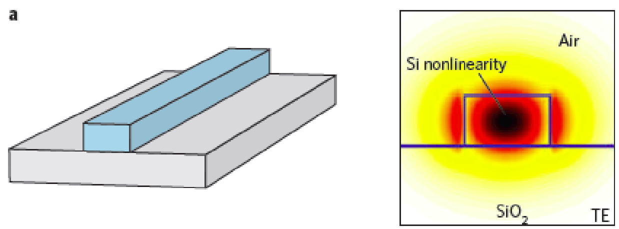
Use Light to Control Light → All-Optical Signal Processing

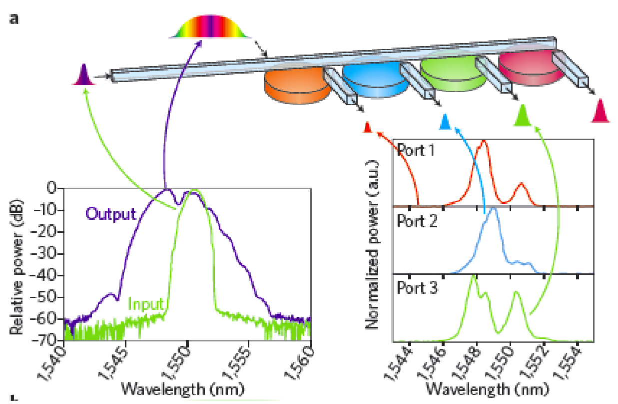
All-Optical Switching: Inorganic Materials

- **Fiber-based AOS:**
  - Mature material technology with some tailorability
  - Fast switching possible
  - Nonlinear response relatively low
  - Relatively large footprint

- **Semiconductor-based AOS**
  - Highly integrable with existing technology
  - Strong confinement of light
  - Material tailorability may be limited
  - Switching response and optical losses can be issues

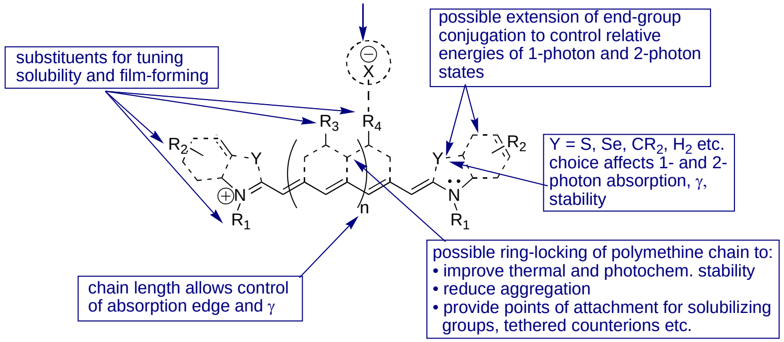






Generate, Transmit, ***Process***

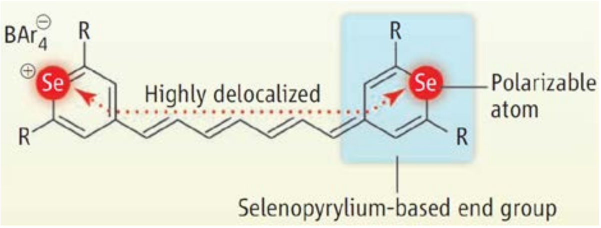
All-Optical Switching: Organic Materials



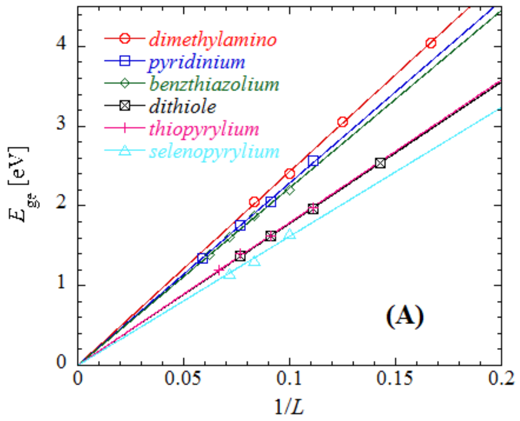
Systematic molecular engineering

- ✓ Nonlinear optical properties
- ✓ Linear optical properties
- ✓ Physical properties

Modification of properties



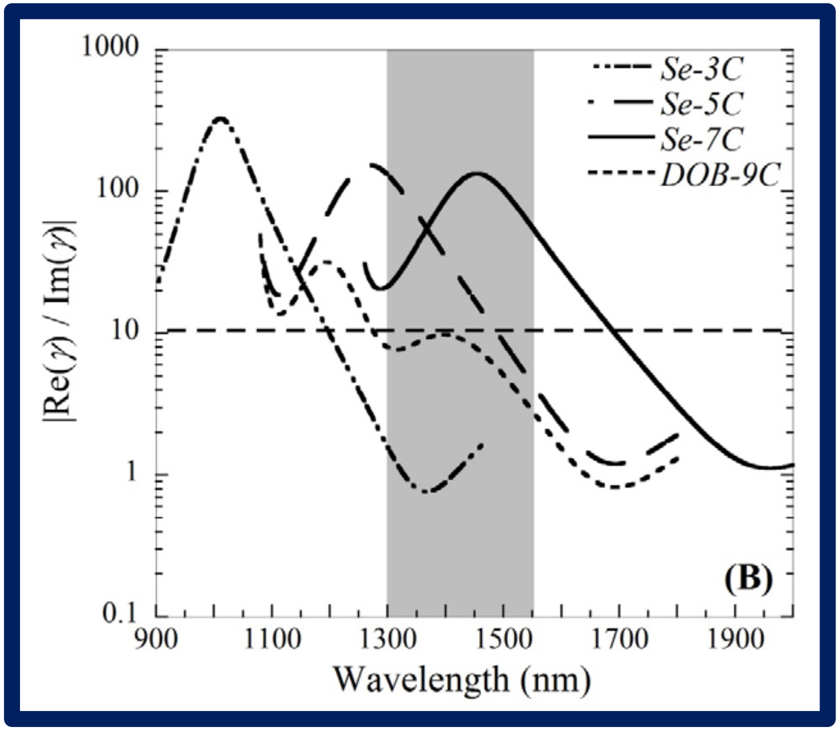
- ✓ Polymethines behave like molecular wires
- ✓ Facile modification of linear and NL optical properties
- ✓ Potential for AOS



$$\mathit{Nonlinearity} \propto L^{7-11}$$

Generate, Transmit, ***Process***

All-Optical Switching: Polymethines

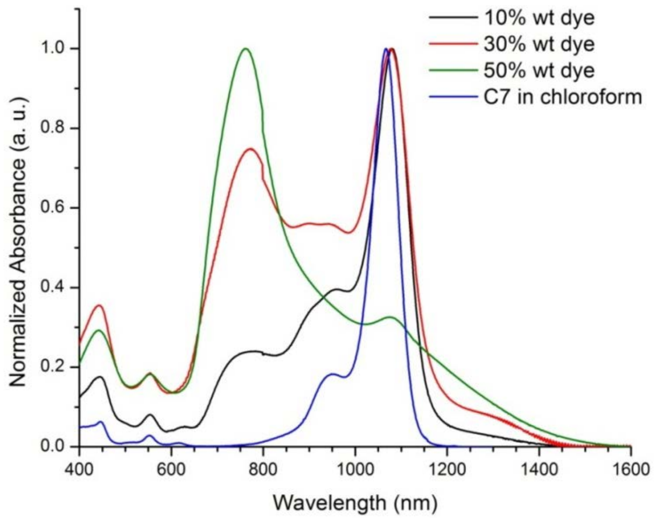


$$n = n_0 + n_2 I$$

$$\alpha = \alpha_0 + \beta I$$

Want this large!

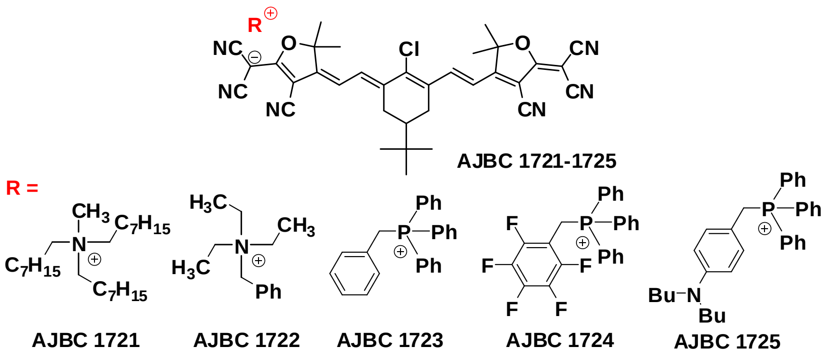
Want this small!

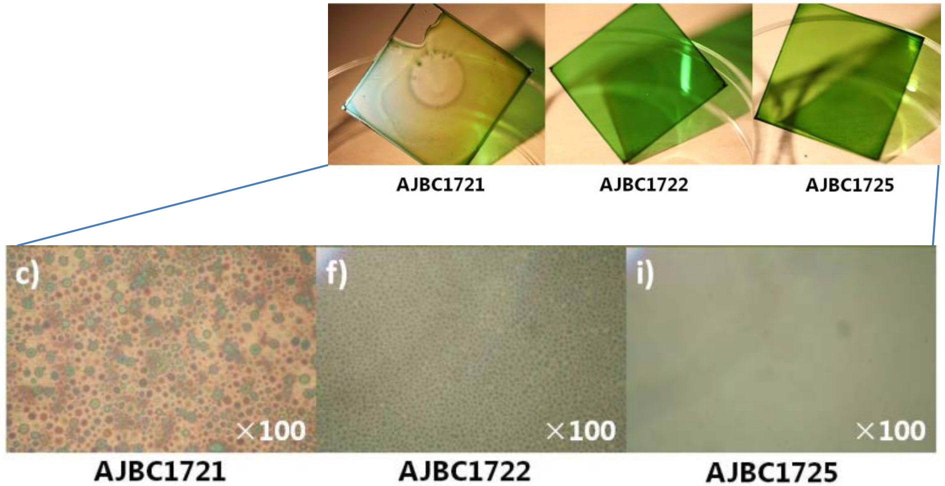


- Achieve large nonlinear refraction while minimizing nonlinear absorption
- Properties are tunable by adjusting molecular length
- Poor translation of microscopic NLO properties to macroscopic NLO properties

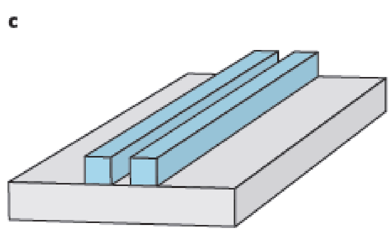
All-Optical Switching: Polymethines

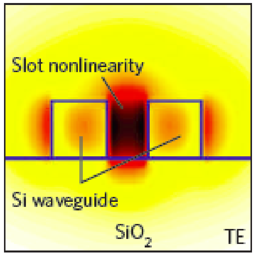
Georgia Tech

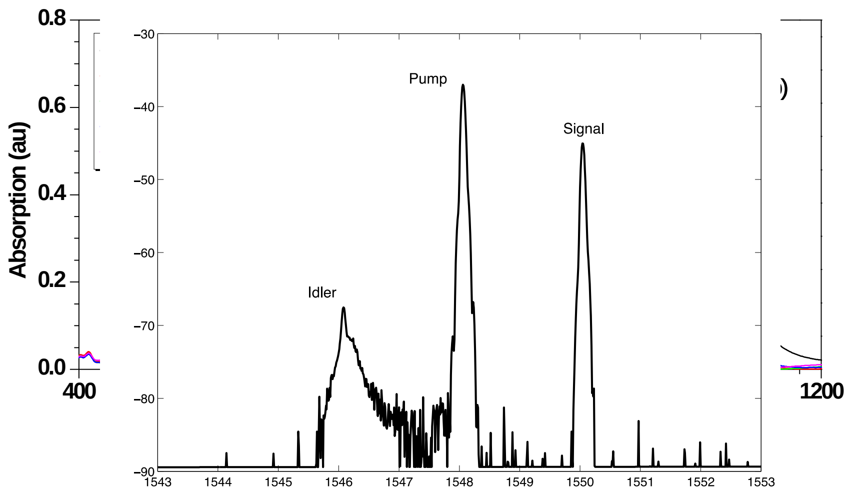




- Drastic reduction in optical loss as compatibility is increased
- Successful translation to macroscopic properties
- Integration into silicon-organic hybrid waveguides allows for NLO response



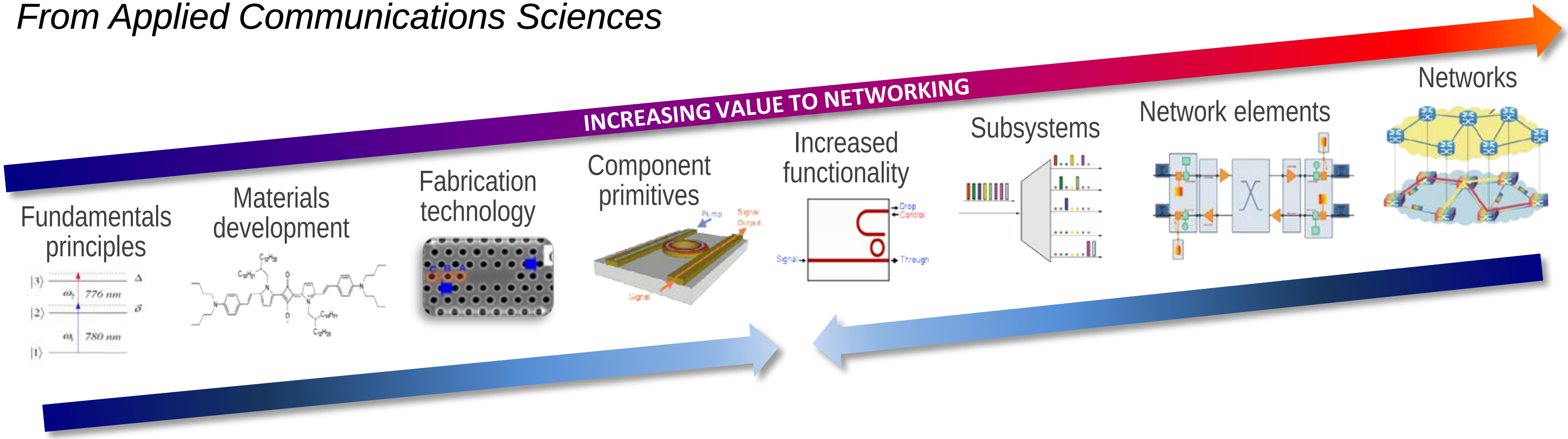




Generate, Transmit, ***Process***

Summary

From Applied Communications Sciences



- ➢ Larger information content requires improvement in technology
- ➢ Photonics could provide viable route for improved processing of information
- ➢ Success in design of organic materials for all-optical switching
- ➢ Key is to identify how innovative device technologies can be integrated into all-optical networks

Acknowledgements

Georgia Tech

- ***Hyeongeu Kim, Jonathan D. Matichak, Seth R. Marder, Joseph W. Perry***
  School of Chemistry and Biochemistry, Center for Organic Photonic and Electronics, Georgia Institute of Technology

- ***Y. Henry Wen, Onur Kuzucu, Alexander Gaeta***
  School of Applied and Engineering Physics, Cornell University

- ***Taige Hou, Carl Poitras, Jaime Cardenas, Michal Lipson**[*]*
  School of Electrical and Computer Engineering, Cornell University
  [*]The Kavli Institute for Nanoscience, Cornell University

- ***Zhong'an Li, Sei-Hum Jang, Jingdong Luo, Yang Liu, Tom Baehr-Jones, Michael Hochberg, Alex K.-Y. Jen***
  Department of Materials Science and Engineering, University of Washington

Research support is gratefully acknowledged from:

NSF-STC on Materials and Devices for Information Technology Research (CMDITR), DMR-0120967

DARPA MORPH Program and ONR (N00014-04-0095 and N00014-06-1-0897)

DARPA ZOE Program (W31P4Q-09-1-0012)

References

1. Telesurgery: http://crie.esarganil.pt/Materiais/L%C3%ADnguas%20Estrangeiras/Online%20Task%20-%20Unit%202-%2010th%20grade/telemedicine.jpg
2. Distance learning: http://www.securedgenetworks.com/Portals/80068/images/education-video-conferencing.jpg
3. RFID: http://www.itu.int/net/pressoffice/pictorial/2011/broadband/downloads/broadband.pdf
4. Global weather: http://brightcove01.brightcove.com/10/260825828001/201201/3647/260825828001_1410139437001_vs-1410139581001.jpg?pubId=260825828001
5. Market Dynamics: http://www.gardnerjones.com/USERIMAGES/marketing_magnifying_glass.jpg
6. Entertainment: http://www.macmechanic.com/wp-content/uploads/2011/02/ATV_TV_Main_Movies_SCREEN.jpg
7. Gaming: http://msnbcmedia2.msn.com/j/msnbc/Components/Photo_StoryLevel/080325/080325-PC-Gaming-hmed-3p.grid-6x2.jpg
8. Data traffic: http://www.infovista.com/Portals/0/graphics/graphics/cp_traffic_scenarios_enlarge.jpg
9. Broadband information: http://www.itu.int/net/pressoffice/pictorial/2011/broadband/index.aspx?lang=en#.USMZz2f6aHs
10. Statistical information: http://www.itu.int/ITU-D/ict/statistics/material/pdf/2011%20Statistical%20highlights_June_2012.pdf
11. E-mag spectrum: http://upload.wikimedia.org/wikipedia/commons/8/8a/Electromagnetic-Spectrum.png
12. Optical fiber: http://en.wikipedia.org/wiki/Optical_fiber
13. Generic switching: http://www.solidsystems.co.kr/images/general_wdmpon.gif
14. ROADM: Applied Communications Sciences
15. DLP: JDS Uniphase via Applied Communications Sciences
16. Fiber optical switching: Rhy_OptComm_1998
17. Silicon photonics: Leuthold_NatPhot_2010
18. Selenopyrylium polymethines for AOS: Hales_Sci_2010
19. TCF polymethines: Li_AdvMat_2012