광통신 및 광신호처리용
광도파로 소자 개론

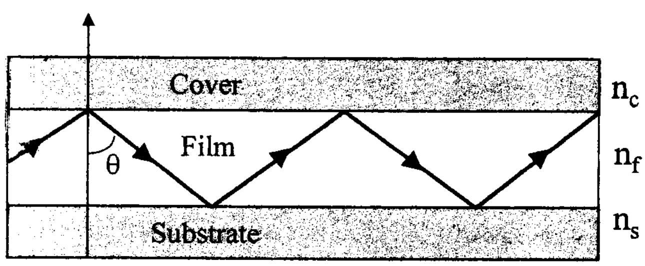
한국과학기술연구원
교 수 신 상 영

Outline

- Introduction (waveguide devices, poling, fabrication methods, etc.)
- Polymer waveguide devices
  - 1xN power splitter
  - Arrayed waveguide grating (AWG) multiplexers / demultiplexers
  - Tunable wavelength filters
  - Add / drop multiplexers
  - Variable optical attenuators
  - Optical switches
  - Optical modulators
  - Polarizers / polarization splitters / polarization converters
- Research projects and commercial efforts
- Examples of market studies
- Conclusion

KAIST

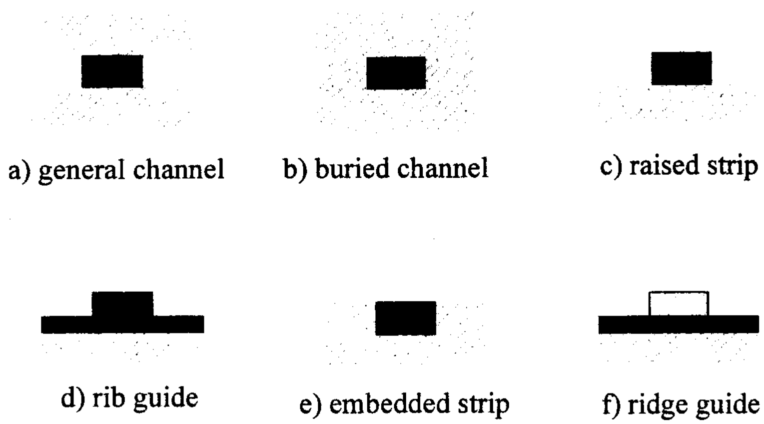
Side-view of a Planar Waveguide



$n_f > n_s, n_c$

KAIST

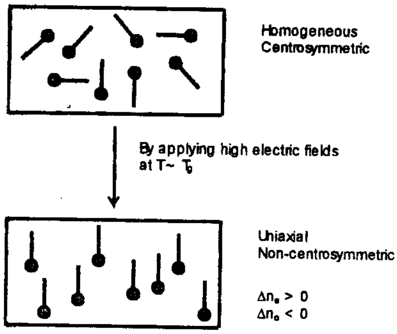
Cross Section of Channel Guide Structures



Waveguide Devices Based on Electro-Optic Polymer

- Advantages
  - High-speed operation
  - Low coupling loss to fibers
  - Potentially large EO coefficients
  - Easy integration with electronic circuits and other optical devices
  - Low cost and mass production
  - Flexible control of optic axis directions
  - Flexible design
- Problems
  - Thermal stability (being improved)
  - Optical damage

Electric Poling in EO Polymers



Alignment of the chromophore molecule parallel to the local poling field

$$n_e = n + \Delta n_p$$
$$n_o = n - \tfrac{1}{2}\Delta n_p$$
$$\Delta n_p \propto |E_p|^2$$

E_p : Local Poling Field

- Induction of EO effect in polymers
- Poling-induced birefringence

KAIST

Electric Poling

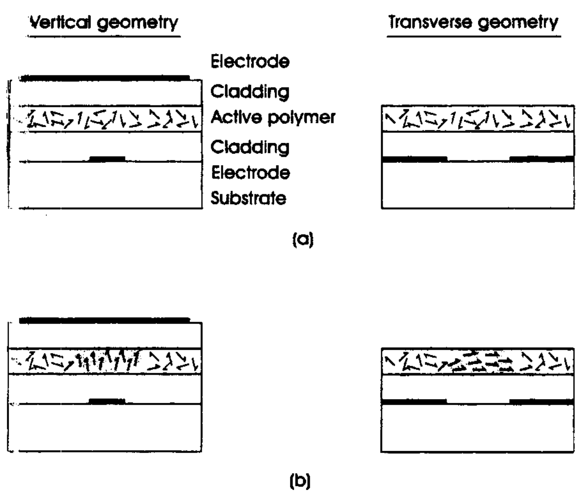
- Corona poling
  - Larger NLO coefficient (owing to increased electric field)
  - Smaller decay constant of poled film
  - Difficult definition of poling area
- Electrode poling
  - Easy definition of poling area

KAIST

Fabrication Methods of Polymeric Waveguides

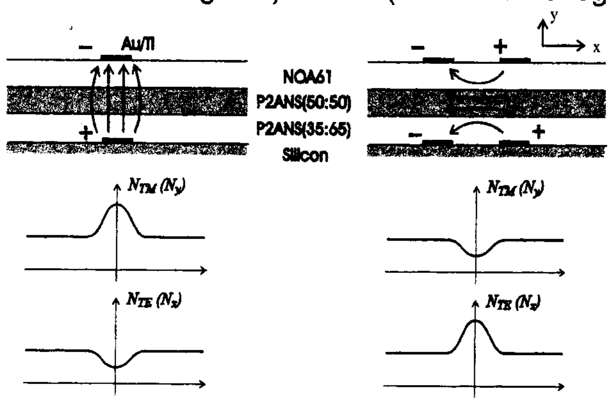
- Electric poling (poling-induced birefringence)
- Photobleaching
- Reactive ion etching
- Photopolymer cladding technique
- Injection moulding

Poling Induced Polymer Waveguides



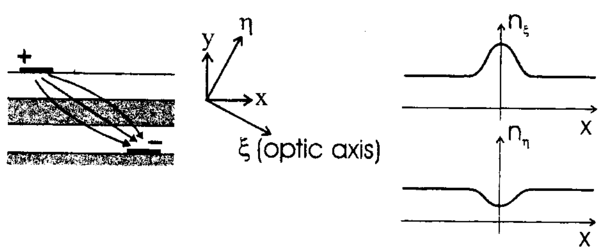
Poling-Induced Birefringence in EO Polymers

- Vertical poling
  (TM mode waveguide)
- Horizontal poling
  (TE mode waveguide)



KAIST

Controllable Optic Axis Direction in Poled Polymer Waveguides

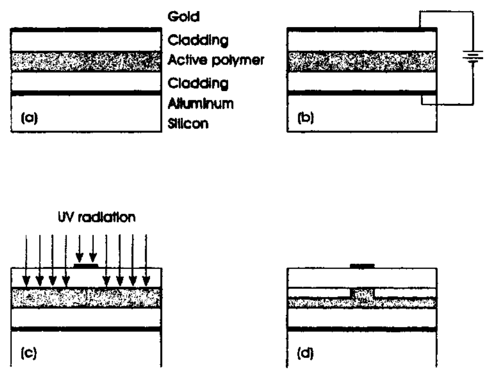


- By designing the electrode structure for poling, it is possible to fabricate a poled polymer waveguide whose optic axis has a desired direction

KAIST

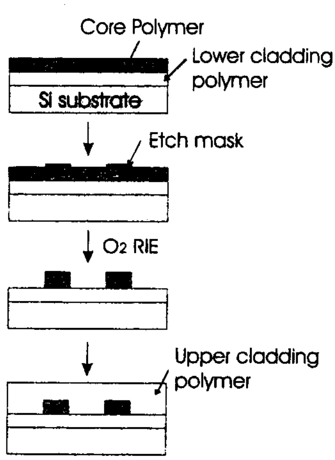
Photobleaching Method

- Photobleaching decreases the refractive index of the polymer
- Favorable for large area waveguide devices
- Most popular way to fabricate the polymeric channel waveguides



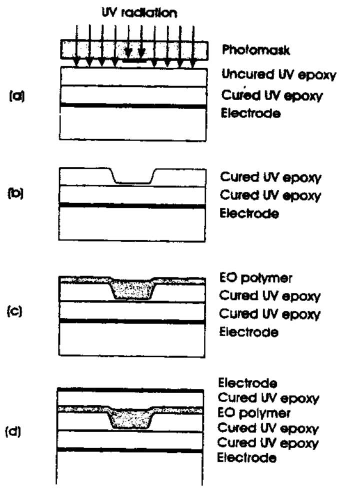
KAIST

Reactive Ion Etching



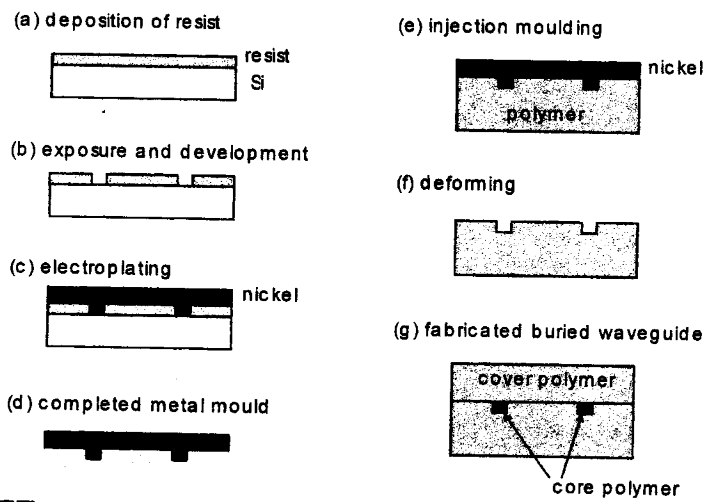
KAIST

Photopolymer Cladding Technique



KAIST

Injection Moulding Technique



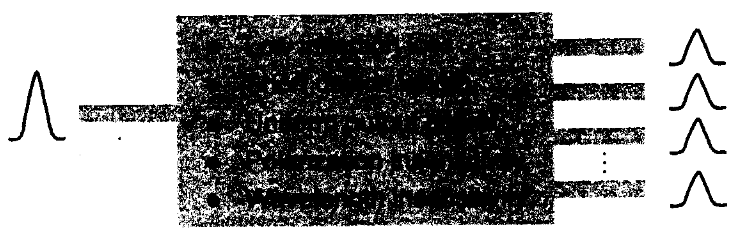
KAIST

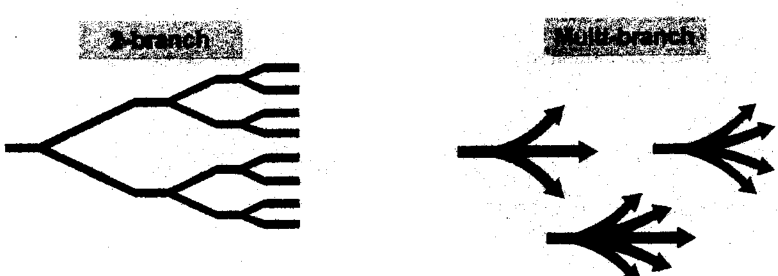
Polymer Waveguide Devices

- 1xN power splitters
- Arrayed waveguide grating (AWG) multiplexers / demultiplexers
- Tunable wavelength filters
- Add / drop multiplexers
- Variable optical attenuators
- Optical switches
- Optical modulators
- Polarizers / polarization splitters / polarization converters

KAIST

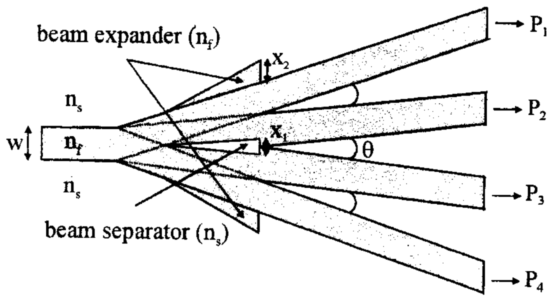
Optical Power Divider





KAIST

Power Divider based on a 4-branch WG

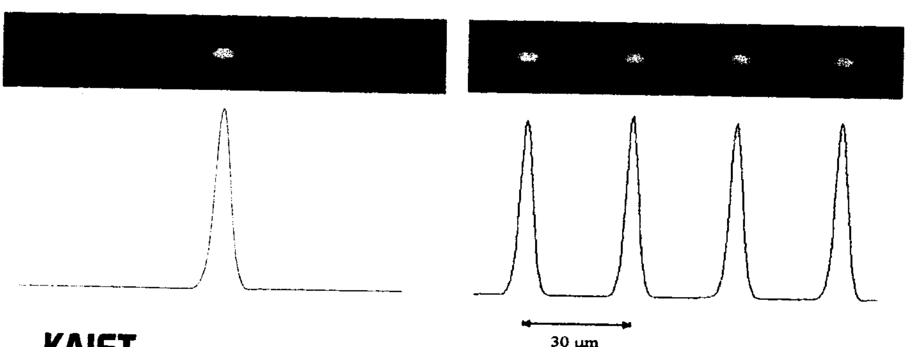


- Configuration
  - w : WG width
  - θ : branch angle
  - x_1 ; beam separator
  - x_2 : beam expander
- Advantages
  - uniform output power
  - simple fabrication
    - without extra process
  - short device length
  - controllability

KAIST

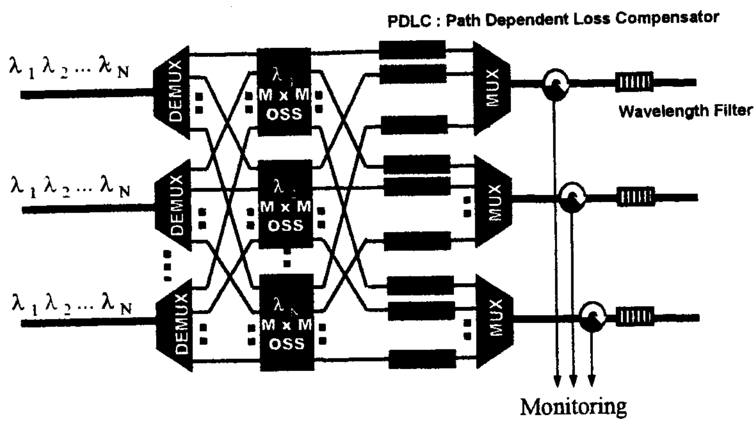
Measurement Results

- Optical Output Power Distribution
  - TE mode (Uniformity = 0.30 dB)
    25.0 : 25.7 : 25.3 : 24.0
  - TM mode (Uniformity = 0.28 dB)
    25.7 : 25.2 : 24.1 : 25.0



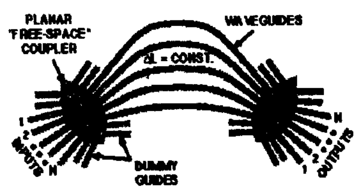
KAIST

Optical Cross-Connect System

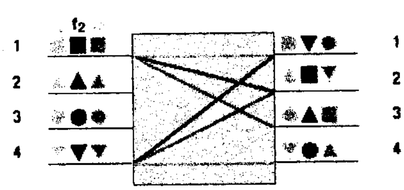


KAIST

Arrayed Waveguide Grating Filter

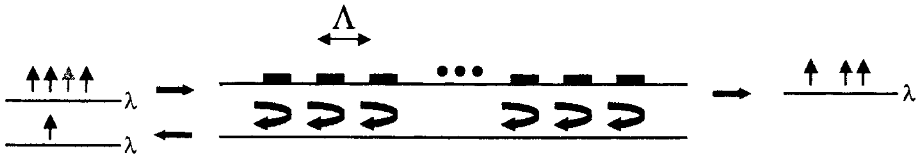


- AT & T AWG Specification
  - 8 or 16 Channels
  - 100 GHz Channel Spacing
  - < 23 dB Crosstalk
  - < 6 dB Insertion Loss



KAIST

Wavelength Filter with Gratings

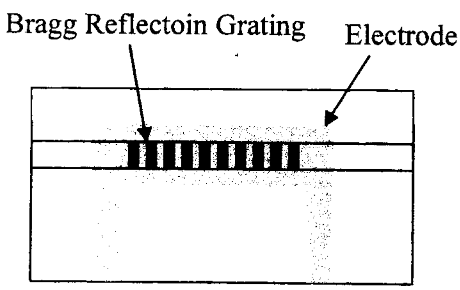


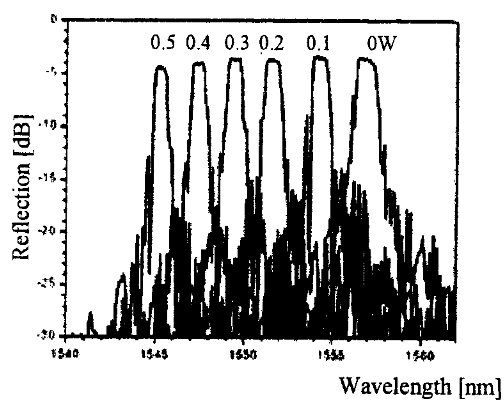
$$\lambda_B = \frac{2\,N_{eff}\,\Lambda}{m}$$

λ_B: Reflected Wavelength
N_{eff}: Effective Refractive Index
Λ: Period of Grating
m: Order of Bragg Reflection

KAIST

Tunable Wavelength Filters



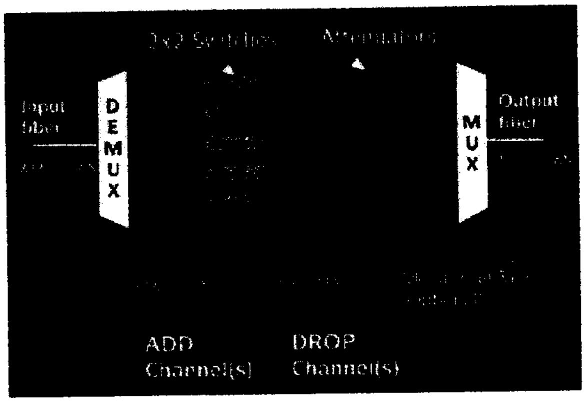


$$\Delta\lambda_B = \frac{2\,\Lambda}{m}\frac{\partial n}{\partial T}\Delta T$$

APL 1998, M.-C. Oh et al.

KAIST

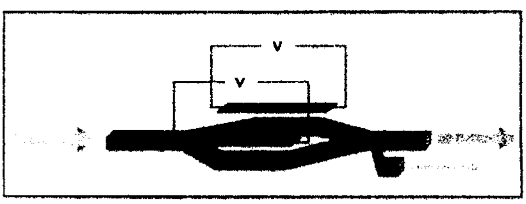
JDS Fitel's COADM
(Configurable Optical Add Drop Multiplexer)



(BeamBox™ Newsletter, June 1998)

KAIST

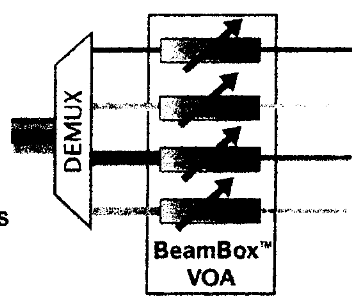
Variable Optical Attenuator
(AKZO NOBEL)



Schematic representation of the BeamBox™ Variable Optical Attenuator

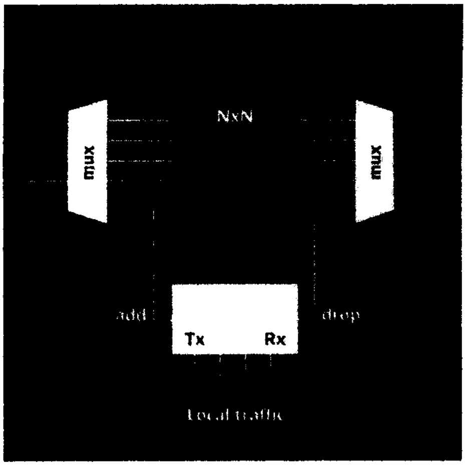
- Mach-Zehnder type

- Applications
  - Optical power leveling in DWDM system
  - Gain control of optical amplifiers
  - Overload prevention of optical receivers

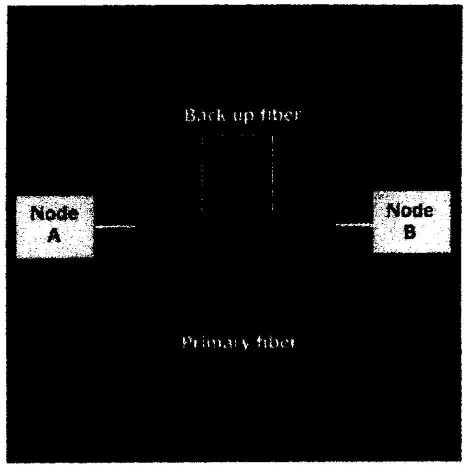


KAIST

Applications of Optical Switches



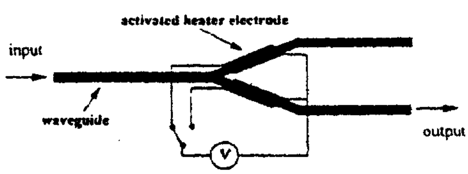
Optical Cross Connect



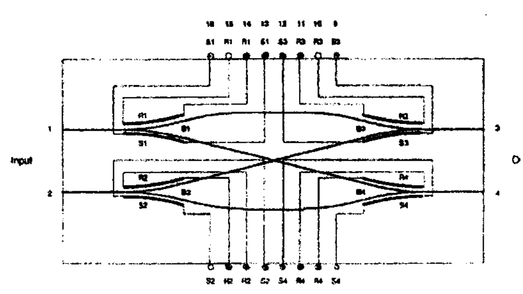
Self-Healing Ring Architecture

KAIST

Configuration of Optical Switch



1×2 Switch

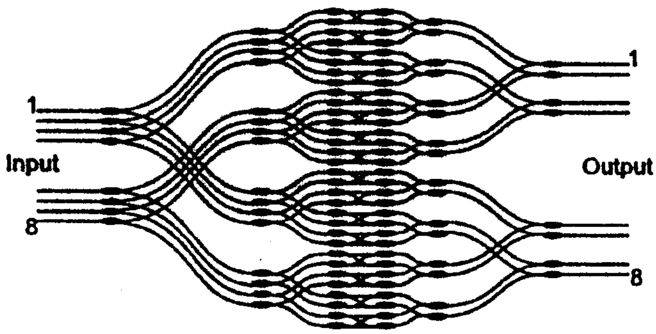


2×2 Switch

KAIST

8X8 Strictly Nonblocking Recursive Tree Structure

- Albert Borreman et al (ECOC'96)



KAIST

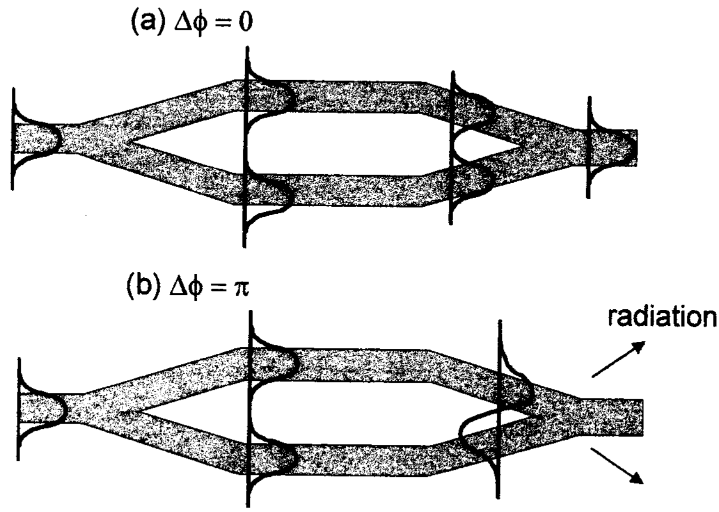
Optical Switches

1×N	Company	Material	Type	Loss [dB]	Crosstalk [dB]	Power [mW]	Voltage [V]
1×2	Akzo	Polymer	Y-branch	≤2	≤-25	250-500 (350)	7-12 (11)
2×2	Akzo	Polymer	Y-branch	≤3.5	≤-30	350-650 (450)	7-12 (11)
1×4	Akzo	Polymer	Y-branch	≤4	≤-25	500-950 (675)	7-12 (11)
2×2	PIRI	Silica WG	Mach-Zehnder	≤1.5	≤-16.5 (-21)	600	5

	Author	Material	Type	Loss [dB]	Crosstalk [dB]	Power [mW]	Ref.
2×2	Suyten	Polymer	X-branch a-s		≤-26	100	SPIE '93
2×2	Keil	Polymer	X-branch a-s	≤4.5	≤-25	90	EL '96
2×2	Hoffman	Silica	X-branch a-s	≤3	-15/-27	1000	ECIO '97

KAIST

Mach-Zehnder Intensity Modulator



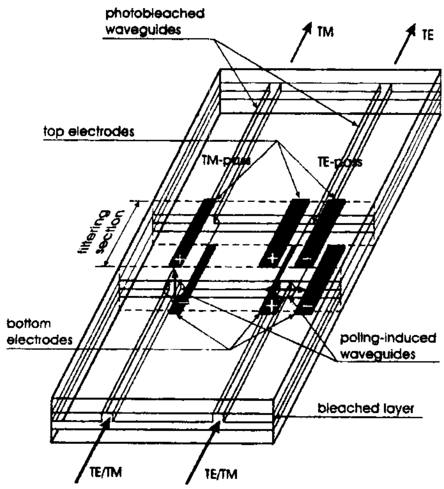
KAIST

Optical Modulators Based on Electro-Optic Polymers

First authur	Organization	Bandwidth	V_π, L	r_{33}[pm/V]	Material	Year
C. C. Teng	Hoechst	40 GHz	10 V, 12 mm	16	P2ANS	1992
Y. Shuto	NTT	> 1 GHz	16 V, 15 mm	20	3RDCVXY	1995
S. Ermer	Lockheed	50 GHz	5 V, 26 mm	.	DCM	1995
W. Wang	UCLA	40 GHz	35 V, 15 mm	12	PUR-DR19	1995
W. Wang	UCLA	60 GHz	.	.	PUR-DR19	1995
W. Wang	UCLA	113 GHz	.	.	PUR-DR19	1997

KAIST

Polymeric Waveguide Polarizers

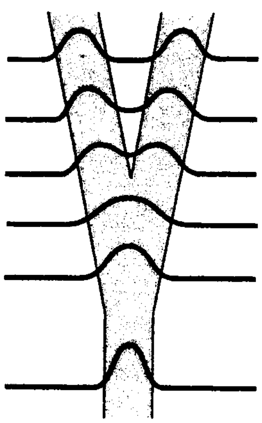


- Poling-induced waveguide connects photo-bleached waveguides
- Photo-bleached waveguide supports both TM and TE modes
- Poling-induced waveguide supports either TM or TE modes
- Vertical poling : TM-pass
  Horizontal poling : TE-pass

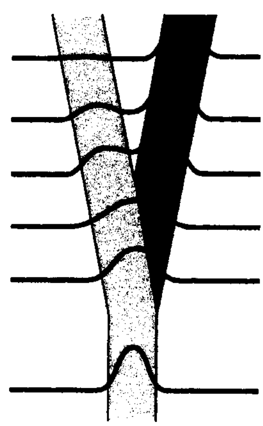
KAIST

Modal Evolution in a Y-Branch Waveguide

- Symmetric

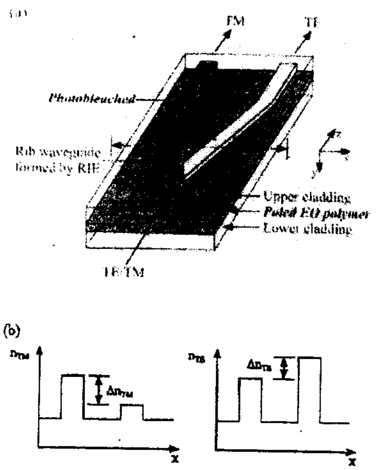


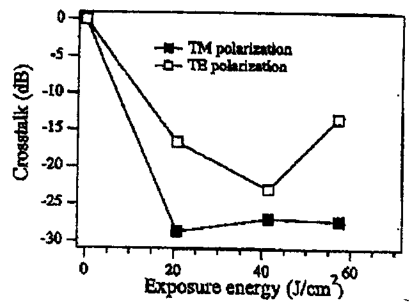
- Asymmetric



KAIST

Waveguide Polarization Splitter in a Poled Electro-Optic Polymer

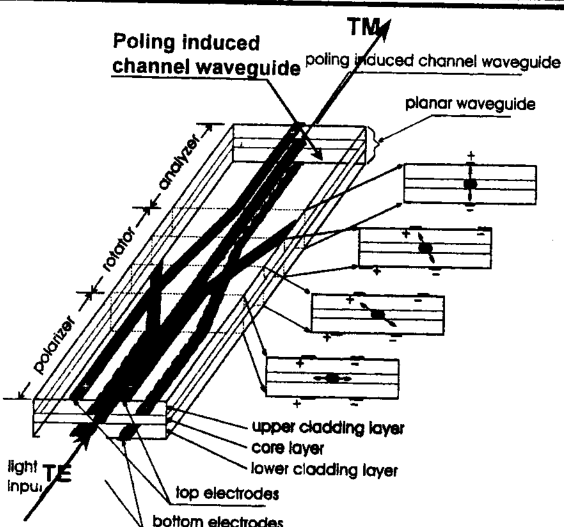




- S. S. Lee et al (APL, 1998)

KAIST

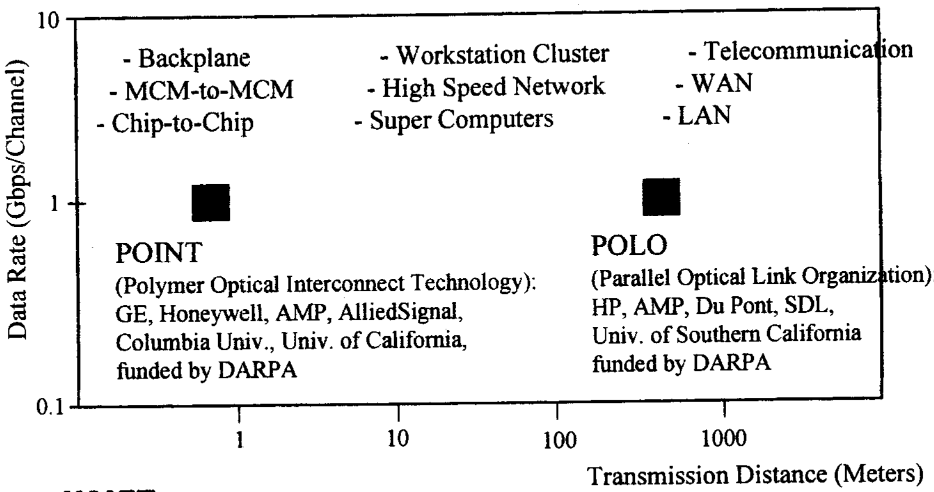
Polymeric Waveguide Polarization Converters



- The electrodes of TE-mode and TM-mode poling-induced waveguides are slowly varied and connected in the rotator section
- After poling, the azimuth angle of the poling-induced optic axis is changed from 0° to 90°
- TE to TM polarization conversion simillar to twisted nematic liquid crystal

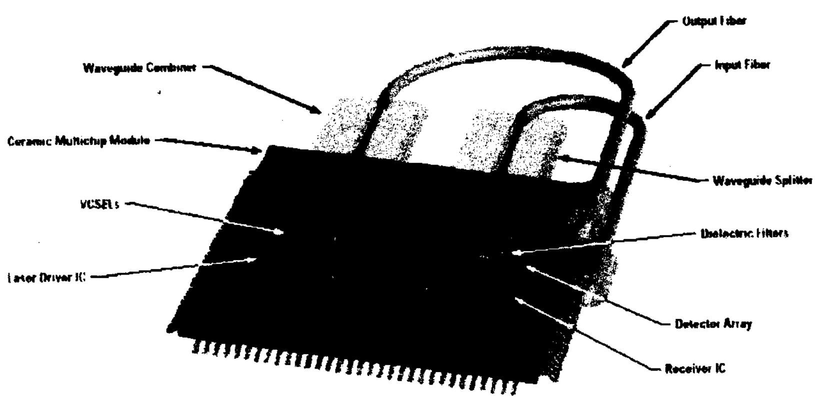
KAIST

Projects Related with Optical Interconnection



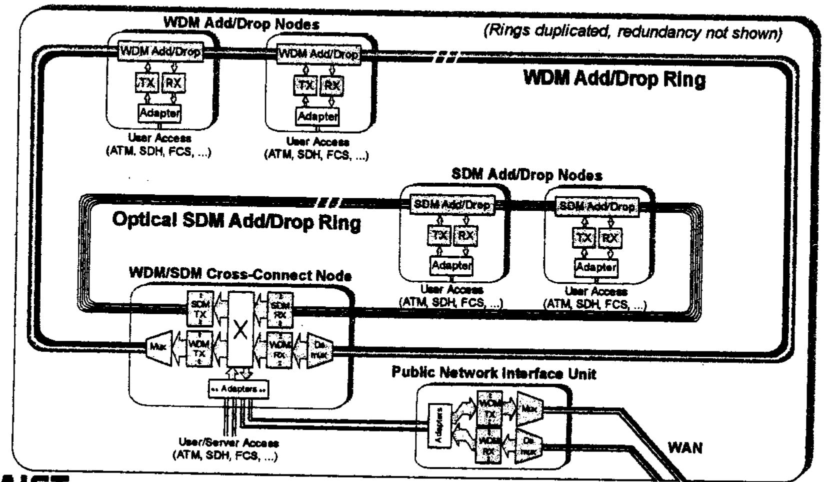
KAIST

SpectraLAN (Hewlett-Packard)



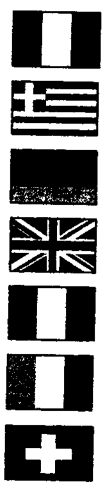
KAIST

Corporate Optical Backbone Networks (COBNET)



KAIST

The Consortium



- Compagnie IBM France
- National Technical University of Athens
- Siemens AG
- GEC Marconi Materials Technology
- GPT Ltd
- British Telecommunications plc
- Siemens Atea
- Italtel Spa
- Nortel plc
- ETH Zurich
- EPF Lausanne
- University of Dortmund
- IBM Zurich Research Laboratory

KAIST

Nonmechanical Switch Components Global Consumption Value Trends

Nonmechanical Switch Component Global Consumption Value Trends, Singlemode Vs. Multimode

	1997		2002		Average Annual Growth Rate %
FIBER INPUT/OUTPUT	$ Million	%	$ Million	%	1997-2002
Single mode	5.4	5.7	39.7	63	49
Multimode	4.1	4.3	23.8	37	41
TOTAL CONSUMPTION	9.5	100	63.5	100	46

NOTE: TOTALS MAY NOT BE EXACT, DUE TO ROUNDING. Source: ElectroniCast Corporation

KAIST

Photonic Switch and Switch Matrix Global Consumption Value Trends

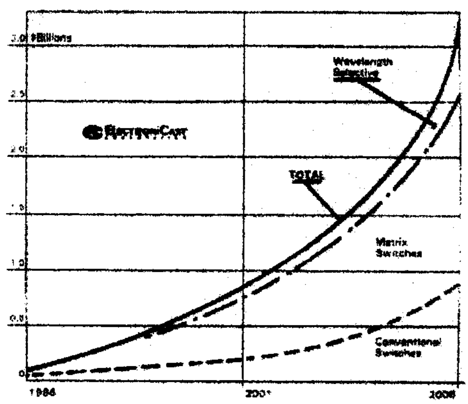


Figure 2. Photonic Switch and Switch Matrix Global Consumption Value Trends

KAIST

Conclusion

- Passive and electro-optic types of polymeric optical waveguide devices have been discussed.
- The devices include
  - 1xN power splitters
  - Arrayed waveguide grating (AWG) multiplexers / demultiplexers
  - Tunable wavelength filters
  - Add / drop multiplexers
  - Variable optical attenuators
  - Optical switches
  - Optical modulators
  - Polarizers / polarization splitters / polarization converters

KAIST