Optical Communication Devices and Materials for Planar Waveguide Circuits

ZENPHOTONICS

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Contents

❑ WDM Optical Network
❑ Material for Optical Networks
❑ Polymers for Optical Devices
(ZEN, ETRI)
❑ Optical Devices with Dolymer
(ZEN, ETRI)

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Introduction

Telecommunication Evolution

1950	1980	2010
Electron	Photon	
TDM	WDM	100Mbps
Analog	Digital	
Voice	Data	Internet 400 times

Photon has higher carrier speed

Photon has a unique property......more wavelength --> more information

Digital process --> clean and higher information

Voice : Data 1:1 --> 1:20 (2010)

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WDM Communiction

•differrent wavelength not interfere each other

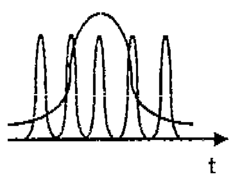
• ultrafast time tech. ⇨ multi wavelength tech.

• Low speed data controll ⇨ Low cost electronics

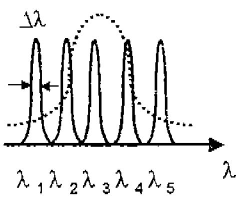
• High capacity data controll (>T bit/s)

• ?●* . . data *

•multiwavelength tech ..... Prism, Fabry-Parot, Mach-Zehnder, AWG



TDM
(Time Division Multiplexing)



WDM
(Wavelength Division Memultiplexing)

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WDM Key Devices

·Discrit Devices

- **Source, Detector, Optical Fiber, Modulator, OXC Optical Switch, (Variable)Attenuator, splitter**
- **Wavelength Mux/Demux, Wavelength (tunable) Filter**
- **Amplifier, All optical devices($\chi^{(3)}$)**

·Integrated Devices

- **ADM(Add/Drop Multiplexer), Wavelength Selector, Wavelength Converter,** 3R(Re-amplification, Re-shaping, Re-timing) Repeater

- RACE : 57 Devices
- ACTS : 54 Devices

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Material for optical system

Material	Process	Strong Point	Weakness
Polymer	Spin coating on smooth surfaces	• simple process • low loss:<0.02 dB/cm • low coupling loss • low price • easily hybrid	• high dimension (−cm) • material supply
silica	-CVD FHD	• low loss (<0.01 dB/cm) • low coupling loss • stabe	• high dimension (~ cm) • high coast • hard hybrid • polraization dependence
SC	·InP substrate -MOCVD -epitaxy	• small size (수 mm) • integrable with active devices	• High loss (>1 dB/cm) • high cost • complicate process • high coupling loss

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Introduction

$$P_i(\omega) = P_i^0 + \chi_{ij}^{(1)} E_j(\omega) + \chi_{ijk}^{(2)} E_j(\omega) E_k(\omega) + \chi_{ijkl}^{(3)} E_j(\omega) E_k(\omega) E_l(\omega) + \cdots$$

Opto-optical (psec.)
THG
FWM

Electro-optical (nsec.)
- EO MZ modulator
- EO switch
SHG
PR

Thermo-optic (msec.)
- TO switch
Plastic Optical Fiber (POF)
Low-loss Polymer Optical Waveguide (LLPOW)
- Passive Optical Devices

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Status

•Historically : 1970 $\chi^{(3)}$ --> 1980 $\chi^{(2)}$ --> 1990 $\chi^{(1)}$

Now : comercialized with low loss polymer(JDS Uniphase)
Future : hybrid/integration with high speed and/or amplifier

•North America :
DARP : amplification, interconnection
POINT,POLO : interconnection - Allied Signal, AMP, HP, Dupont
NIST : ATP(Advanced Technology Programs) : $10M

•Japan : NTT, Hitachi

•Europe : RACE, ACTS project
AKZO : amplifier

•Domestic : ETRI, KAIST, Samsung, LG, Zen Photonics

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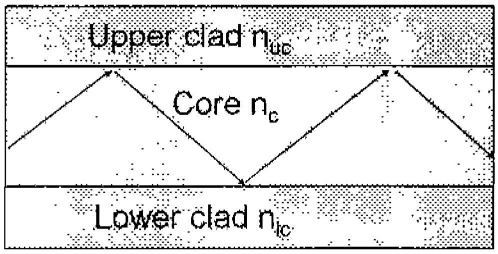
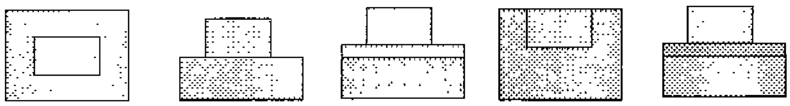
Planar waveguide



$n_c > n_{uc}$, n_{lc}



buried channel | raised strip | rib guide | embedded strip | ridge guide

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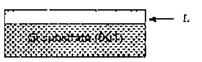
Waveguide formation

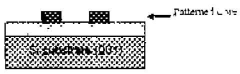
- Reactive Ion etching
- Photobleaching
- Electric Poling
- Injection moulding

1. Spin coating of lower clad layer



2. Spin coating of core layer

3. Patterning



4. Spin coating of upper clad layer

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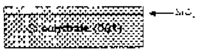
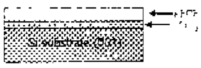
RIE

1. substrate

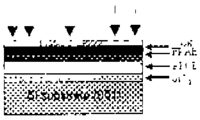


2. Spin coating of lower clad layer

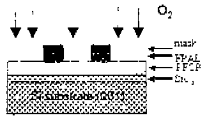


3. Spin coating of core layer

4. Photo lithography



5. RIE of core layer



6. Spin coating of upper clad layer

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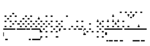
Injection moulding

1. Deposit resist

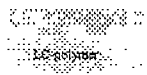
2. Patterning resist

3. Electro plating

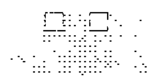
4. Metal mould



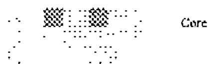
5. Injection moulding



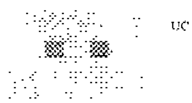
6. Deforming



7. Core deposition



8. UC



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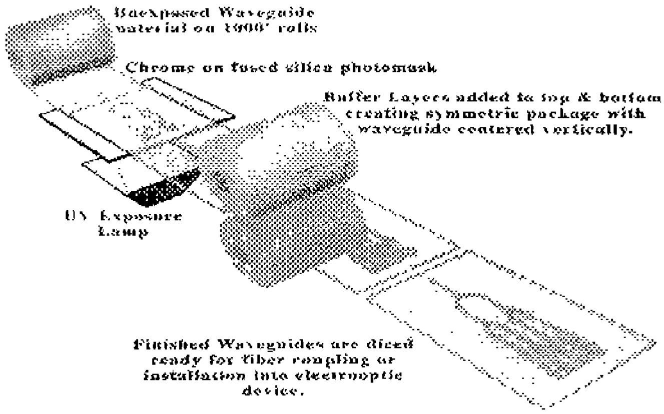
Fabrication of Devices(Multimode)



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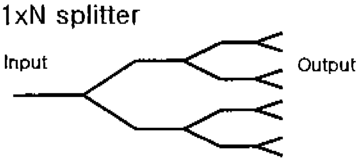
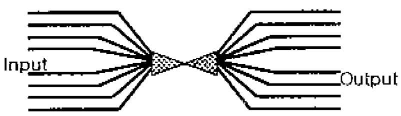
Basic structure(I)

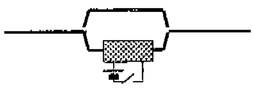
1xN splitter



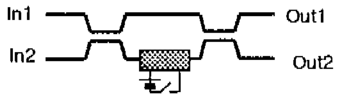
NxN star coupler



MZ modulator



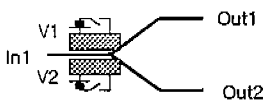
2x2 switch (Interferometer)



V=0 : In1 ←→ Out2

V=V : In1 ←→ Out1

1x2 switch(DOS)



V=0 : In1 → Out1,Out2

V1=V : In1 → Out2

V2=V : In1 → Out1

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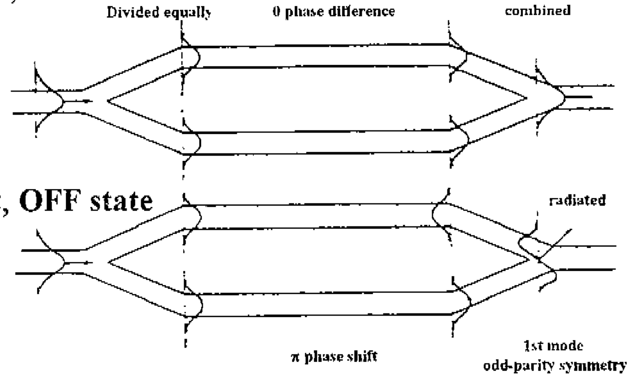
Single Mode Waveguide Mach-Zehnder Modulator

$\Delta\phi = 0$, ON state



$\Delta\phi = \pi$, OFF state

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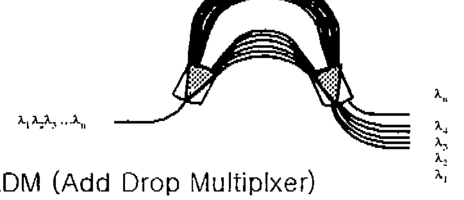
Basic structure(II)

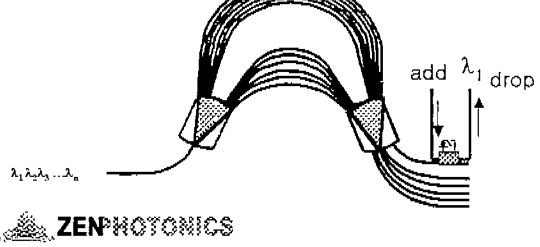
1xN AWG (Arrayed Waveguide Grating)



Wavelength switching:

different λ -> different channel

ADM (Add Drop Multiplxer)



V=0 : AWG

V=V : add or drop specific λ

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Requirements of optical waveguide polymers

- Low optical propagation loss at 1.3 or 1.55 μm wavelength (<0.5 dB/cm)
- Thermal stability at operating temperature (T_d > 300 °C)
- Precise refractive index controllability
- Low birefringence (Polarization independent, $\Delta n < 0.0002$)
- Film formability, Multi-layer formability
- Thickness controllability, Dimensional flexibility
- Adhesion properties, Substrate compatibility
- Chemical & humidity resistance
- Gapfilling or planarization ability
- Cost effective technology (facile synthesis and processing)

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Optical Loss in the polymer waveguide

$$L_{\text{waveguide}} = L_{\text{absorption}} + L_{\text{scattering}} + L_{\text{extrinstic}}$$

$L_{\text{absorption}}$ = Electronic Absorption (n-π*, π-π*, UV-visible)
+ Vibration Absorption (NIR)
$L_{\text{scattering}}$ = Rayleigh Scattering (crystallinity of the polymer)
$L_{\text{extrinstic}}$ = Waveguide roughtness, voids, crack, impurity

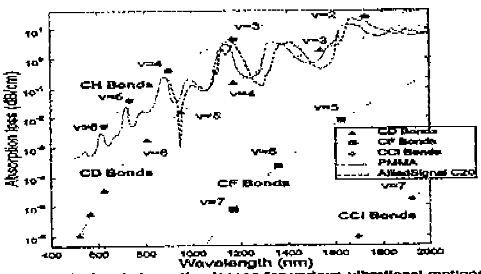

Fig. 3. Calculated absorption losses for various vibrational motions normalized to the observed absorption loss for PMMA. Also shown are experimental losses for PMMA and for a non-modified AlliedSignal polymer, an acrylate with a comparable concentration of CH bonds.

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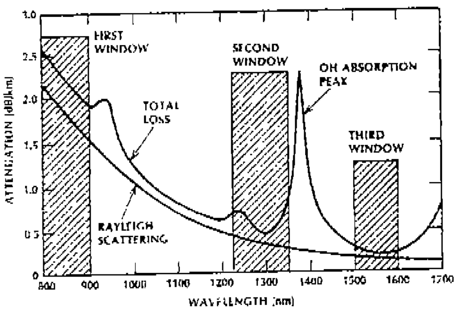
Attenuation of Optical Fiber

Optical Communications : 830 nm → 1300 nm → 1550 nm



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Low loss optical polymer development

Institute	Materials	Thermal Stability	Birefringence	Optical loss (dB/cm)
NTT	Deuterated Fluoro acrylate polymer	Tg = 114 °C	Δn < 10	0.1 @ 1.3 μm 1.35 @ 1.55 μm
	Perfluorinated polyimides	Tg = 309 °C	Δn = 0.008	0.3 @ 1.3 μm 0.6 @ 1.55 μm
	Silicone resin	Td > 400 °C	Δn < 10	0.16 @ 1.3 μm 0.52 @ 1.55 μm
JDS Uniphase (Akzo Nobel)	Halogenated UV curable polycarbonate	Tg > 150 °C	Unknown	< 0.25 @ 1.55 μm (estimated)
Corning (AlliedSignal)	UV curable fluorinated acrylate	Td > 350 °C	Δn = 0.0008	0.03 @ 1.3 μm 0.06 @ 1.55 μm
Dow Chemical	Perfluorocyclobutane (PFCB series)	Tg > 400 °C	Δn = 0.0008 ~ 0.002	0.25 @ 1.3 μm
BFG/LMC	Fluorinated polynorbornene	Tg = 290 ~ 360 °C	Δn = 0.0002	< 0.5 @ 1.55 μm
Ericsson/IBM	Fluorostyrene copolymer	Td > 350 °C	Δn = 4 x 10	0.39 @ 1.32 μm 0.42 @ 1.55 μm
ZenPhotonics (ETRI)	Thermal curable fluorinated polyether	Td > 400 °C	Δn = 0.002 ~ 0.004	0.14 @ 1.3 μm 0.28 @ 1.55 μm
Samsung	Chloro fluoro polyimides	Tg = 350 °C	Δn = 0.01	0.38 @ 1.55 μm

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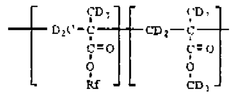
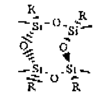
NTT Materials



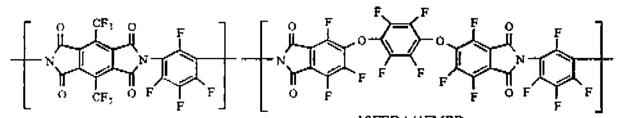
R_f Perfluoroalkyl

PFPMA

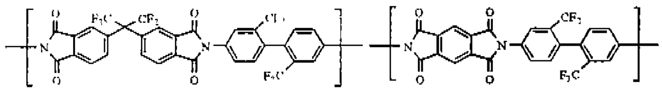


Deuterated polysiloxane.
Phenylsilsesquioxane (PPSQ)

R = deuterated phenyl $PhCl_3$



10FEDA/4FMPD



6FDA/TFDB   PMDA/TFDB

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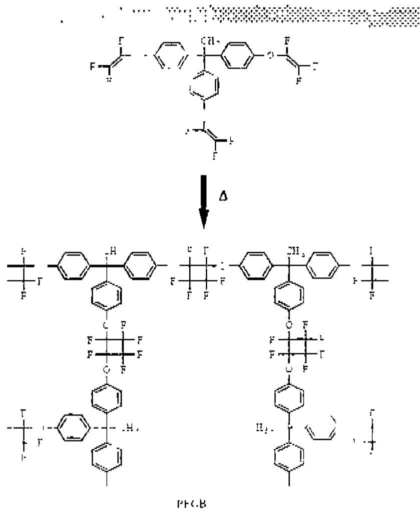
Dow Chemical Materials



PFCB

Features of Dow Chemical

- Refractive index: 1.4898 @ 1.55 μm.
- Low birefringence:
  - ~ 0.0008 @ 1.55 μm, 230 °C.
  - ~ 0.0022 @ 1.55 μm, 250 °C.
- Low water absorption: 0.021 %
- Low intrinsic loss:
  - < 0.2 dB/cm @ 1.3 μm.
- High thermal stability: Tg = 400 °C
- Mechanical flexibility and toughness
- Good gap fillability.

References

- K. Petermann etal. *Electron. Lett.*, 33, 518, (1997)
- A.P. Kennedy etal. *J. Polym. Sci., Polym. Chem.* 31, 3465 (1993)

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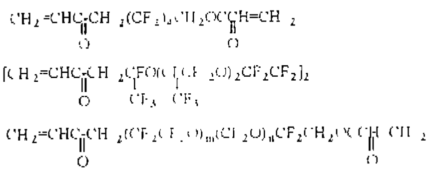
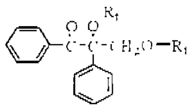
Corning (AlliedSignal) Materials

Fluorinated Acrylate prepolymer



Photointiators



R_f = perfluoroalkyl

Features of AlliedSignal

- Precise refractive index control
  continuous range 1.30 ~ 1.60
- Low birefringence:
  < 0.0008 @ 543.5nm
- High contrast photolithography
  suitable for UV laser curing
- Extremely low intrinsic loss
  loss below 0.03 dB/cm at 1.3 μm.
  loss below 0.05 dB/cm at 1.55 μm.
- High thermal stability: > 300 °C
- Mechanical flexibility and toughness

References

- C. Wu etal. *US Patent*. 5,274,179 (1993)
- L. Eldada etal. *SPIE*, 3006, 344 (1997)
- L. Eldada etal. *J. Lightwave Technol.* 14, 1704 (1996)

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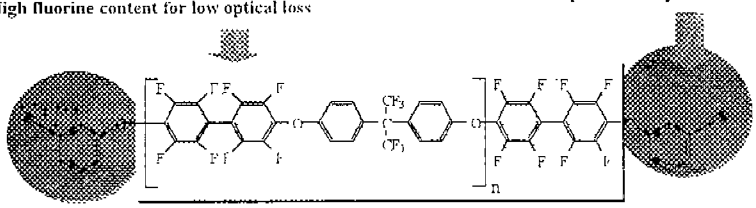
Basic chemical structure

Fluorinated poly(arylene ether)s with ethynyl group

- High thermal stability
- Good mechanical properties
- Low moisture absorption
- low dielectric constant
- High fluorine content for low optical loss

- Good chemical resistance
- Good gapfilling ability
- Increased adhesion property
- Good processablity



Thermal curing

Crosslinked FPAE-EP polymers

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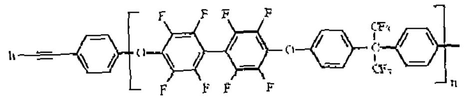
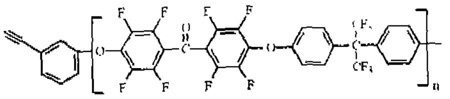
Synthesized Materials

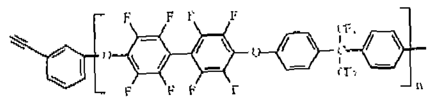
Fluorinated Polyether series



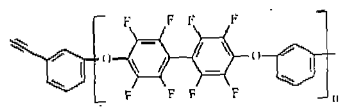
FPAE-PEP; M_n =8,540, M_w/M_n =1.87
Tc > 320 °C



FPEK-EP; M_n =6,700, M_w/M_n =1.76
Tc > 235 °C



FPAE-EP; M_n =8,940 M_w/M_n =1.56
Tc > 240 °C



FPAE(RC100)-EP; M_n =8,680, M_w/M_n =1.61
Tc > 240 °C

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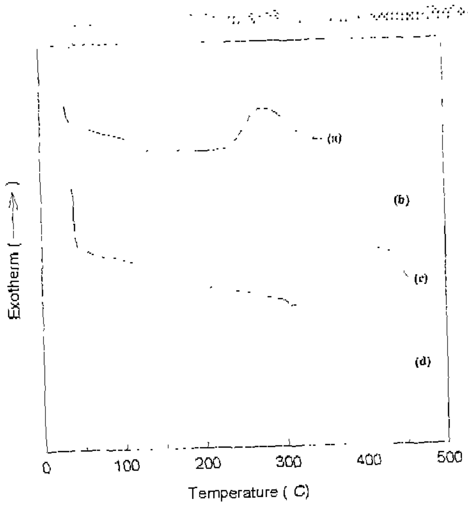
DSC thermograms



(a) = first scan of the FPEK-EP
(b) = second scan of the FPEK-EP
(c) = first scan of the FPAE-PEP
(d) = second scan of the FPAE-PEP
scan rate = 10 °C/min.

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TGA thermograms

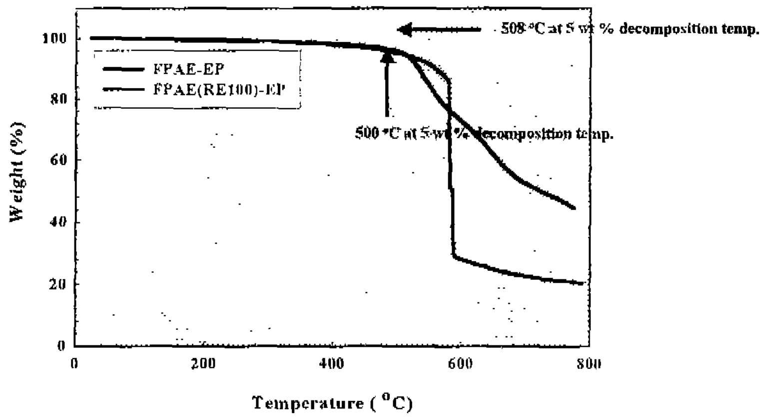

Fig. TGA curve of the polymers under nitrogen at a heating rate of 10 °C/min

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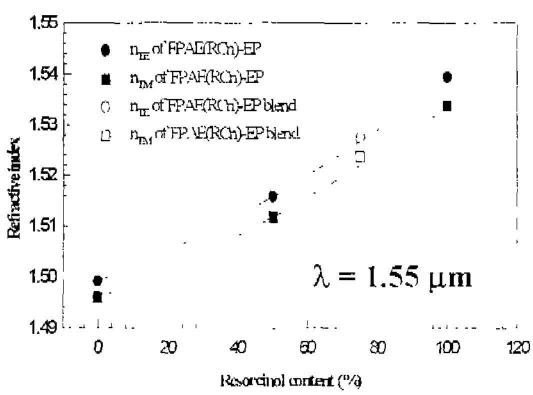
Refractive index control



Precise refractive index control

- Copolymerization of diol monomers
- Polymer blend

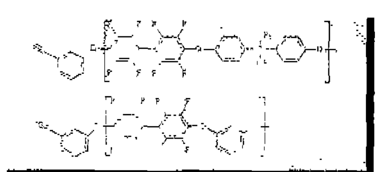


Fig. Refractive index of the FPAE-EP polymers as a contents of resorcinol group

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Long-term refractive index stability

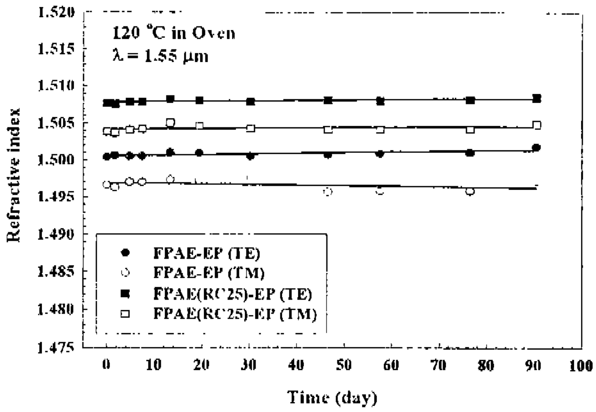

Fig. Refractive index change of the FPAE-EP films during high temperature storage at 120 °C

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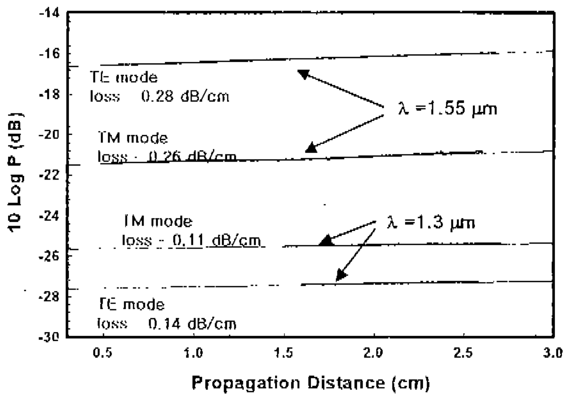
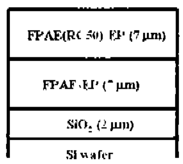
Optical propagation loss



Slap waveguide structure



Immersion Technique;
reported by C.C.Teng
Applied Optics, 32 (7), 1051, 1993

Fig. Optical propagation loss of slap waveguide FPAE(RC50)-EP film

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Summary of developed Polymers

Optical Properties	Propagation loss (waveguide)	0.2 ~ 0.3 dB/cm @ 1.55 mm 0.1 ~ 0.15 dB/cm @ 1.30 mm
	Refractive index range	1.48 ~ 1.54 @ 1.55 mm
	Intrinsic birefrinence	0.002 ~ 0.004
	Thermooptic coefficient	> -1 x 10^{-4}
Thermal Properties	Weight loss temp. (2 %)	480 °C
	Tm (after curing)	none
	Processing Temp.	< 250 °C
Solution Properties	Solution Viscosity	250 ~ 500 cps
	Solid content	35 wt %
Chemical Properties	Solvent resistant	No cracking
	Hydrolytic stability	No cracking
	Water absorption	< 1 % (100 °C, 12 hr.)
Electrical Properties	Dielectric constant	< 2.6 (10 kHz, 30 °C)
	Loss tangent	< 0.001

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Development Optical Devices at ZEN, ETRI

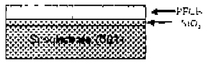
- ❑Optical Switch
- ❑Optical Variable Attenuator
- ❑Wavelength Mux/Demux
- ❑Tunabel Wavelength Filter

ZENPHOTONICS 32

Device fabrication procedure

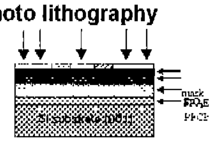
1. substrate

2. Spin coating of lower clad layer

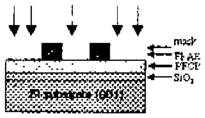


3. Spin coating of core layer

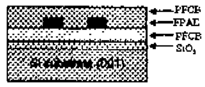
4. Photo lithography



5. RIE of core layer



6. Spin coating of upper clad layer

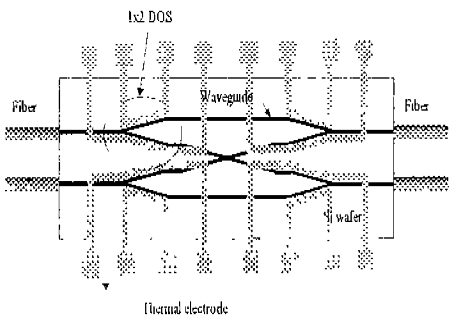


7. Fiber coupling

8. Packaging/Stability

ZENPHOTONICS

Optical Switch(DOS)

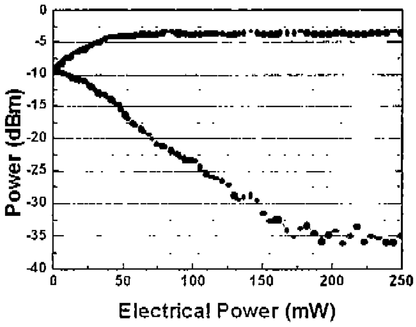


Applications
- WDM system
  ADM, OXC, by pass, optical system
- Radar system
  RF PAA(Phase Arrayed Antenna)

ZENPHOTONICS

2x2 Digital Optical Switch

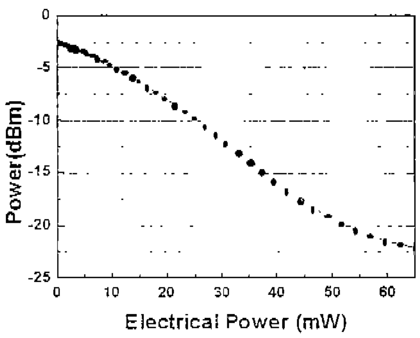
- Four 1x2 switches
- Insertion Loss : < 3.5 dB
- Cross-talk : >30 dB
- Switching Power : < 300 mW
- Switching time : < 3 msec
- PDL : < 0.3 dB
- Simple connection (3 electrical ports)



ZENPHOTONICS

Variable Attenuator

- Insertion Loss : < 2.5 dB
- Attenuation range : > 20 dB
- Driving power : < 65 mW
- Response time : < 5 msec
- Simple connection (2 electrical ports)



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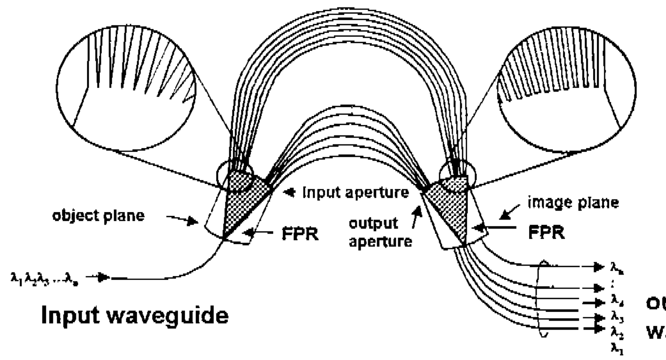
Wavelength Mux/Demus Structure



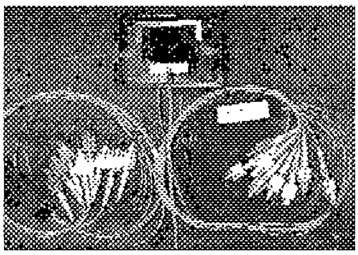
$$\frac{\Delta x}{\Delta \lambda} = \frac{fm}{nd}$$

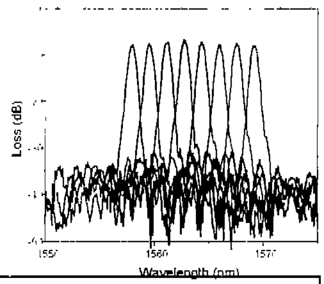
f : focal length
m : deflection order
n : refractive index
d : path difference

chip size : 60x26 mm²

AWG

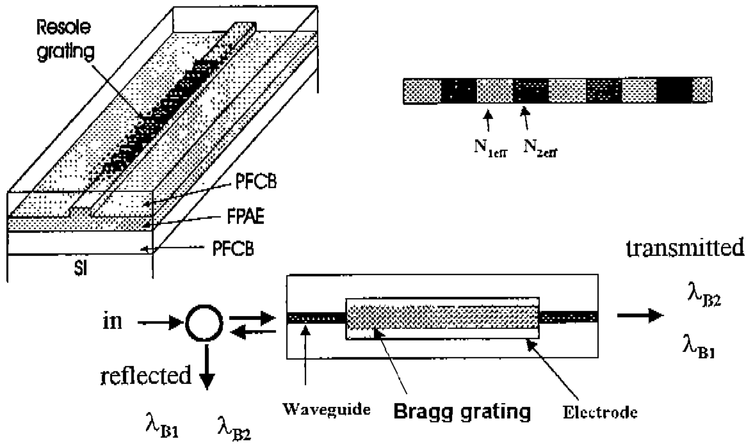
AWG wavelength multiplexer





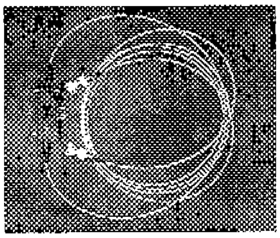
Characteristics:
channel: 1x8, size: 40x15 mm^2, center wavelength: 1562 nm,
channel spacing: 1.6 nm, cross-talk: - 25 dB, insertion loss: 7~8 dB

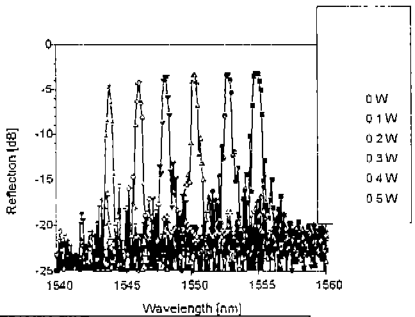
Basic structure for TF



TF

Tunable wavelength filter



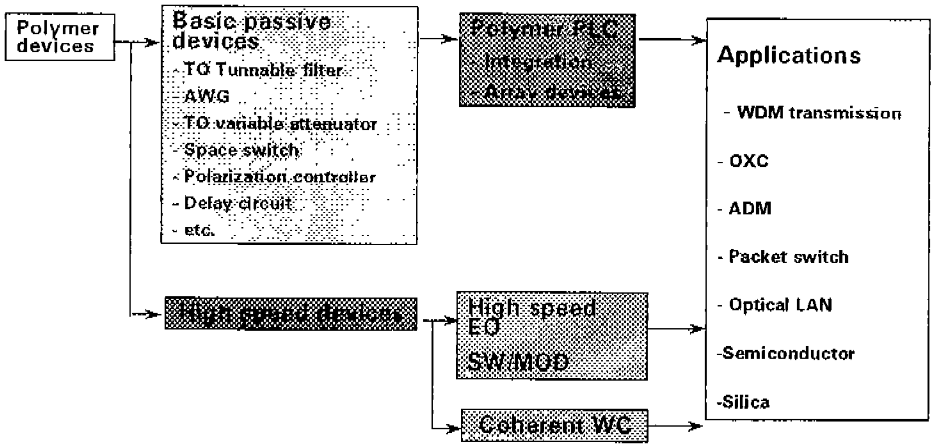


Characteristics:

Tuning range:>10 nm, band width: 0.4 nm, insertion loss: 3.2 dB

Tuning power: 20 nm/W, loss variation : 1 dB

Future possibilities



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