INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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WINTER COLLEGE ON
LASER PHYSICS: SEMICONDUCTOR LASERS
AND INTEGRATED OPTICS

(22 February - 11 March 1988)

INTEGRATED OPTICS

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ICTP WINTER COLLEGE 1988 :

SEMICONDUCTOR LASERS AND INTEGRATED OPTICS

INTEGRATED OPTICS :

COMPONENTS AND DEVICES II

- ACTIVE DEVICES
- MULTIFUNCTIONAL DEVICES

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CSELT - TORINO (I)

ACTIVE DEVICES FOR INTEGRATED OPTICS

- LASER SOURCES
- AMPLIFIERS
- PHOTODETECTORS

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- POLARIZATION CONTROLLERS
- TUNABLE FILTERS / SPLITTERS

MAIN INTEREST FOR ACTIVE DEVICES :

- POSSIBILITY OF FULLY MONOLITHICAL INTEGRATION OF COMPLETE UNITS, SUCH AS:
  - TRANSMITTERS
  - RECEIVERS
  - SIGNAL REGENERATORS / PROCESSORS
  - DEVICES WITH INTERNAL OPTICAL AMPLIFICATION

OPTICAL INTEGRATED SOURCES

MAIN REQUIREMENTS:

- STRUCTURES MUST BE ARBITRARILY PLACED ON SUBSTRATE (NOT NECESSARILY ON CHIP EDGE)
- FABRICATION STEPS MUST BE COMPATIBLE WITH FABRICATION OF OTHER COMPONENTS AND DEVICES (OPTICAL AND/OR ELECTRONIC)

DIRECT CONSEQUENCES:

- CONVENTIONAL CLEAVED-FACET MIRRORS ARE NOT USABLE FOR LASER RESONATORS
- MULTI-STEP EPITAXIAL PROCESSES ARE REQUIRED
- STRUCTURES COMPATIBLE WITH SEMI-INSULATING SUBSTRATES ARE REQUIRED IN SOME CASES
- OUTPUT WAVEGUIDE MUST BE OF DIFFERENT COMPOSITION FROM ACTIVE LAYER FOR LOW LOSS (ACTIVE LAYER IS STRONGLY ABSORBING WHEN NOT PUMPED)

INTEGRATED LASERS

TECHNIQUES FOR RESONATOR FABRICATION

LOCALIZED MIRRORS:

- ETCHED MIRRORS
  - BY CHEMICAL ETCHING
  - BY ION MILLING
- MICROCLEAVED MIRRORS: BY ULTRASONIC CLEAVING OF BRIDGE/CANTILEVER STRUCTURES

DISTRIBUTED MIRRORS:

- DISTRIBUTED BRAGG REFLECTORS (GRATING OUTSIDE GAIN REGION)
- DISTRIBUTED FEEDBACK (GRATING INSIDE THE GAIN REGION)

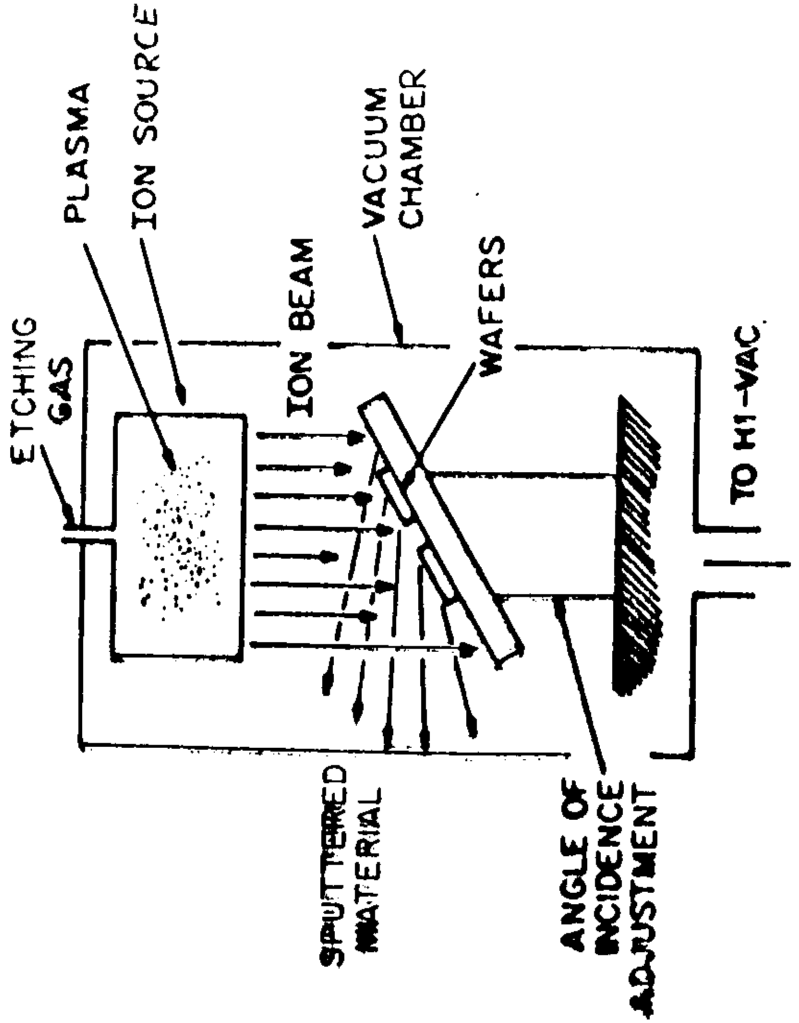
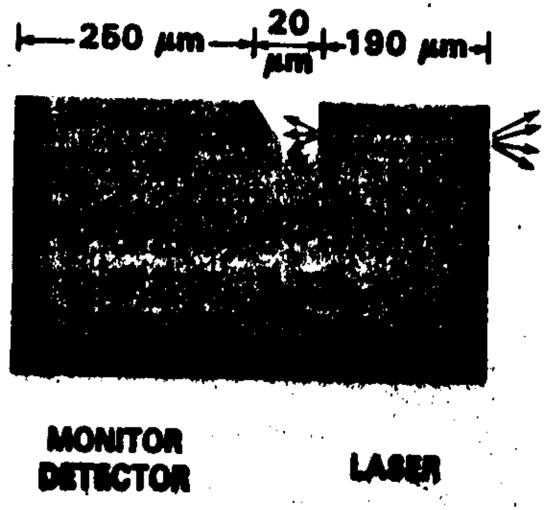
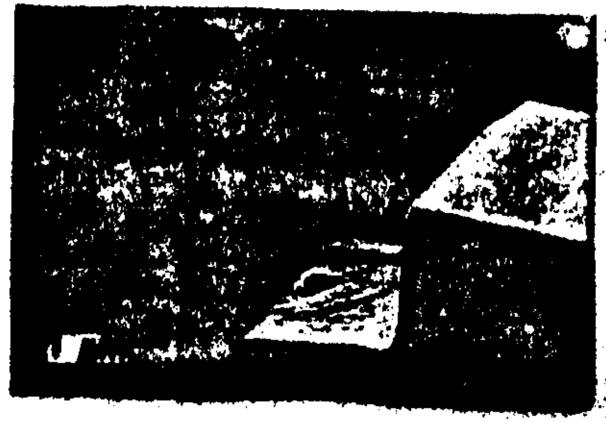


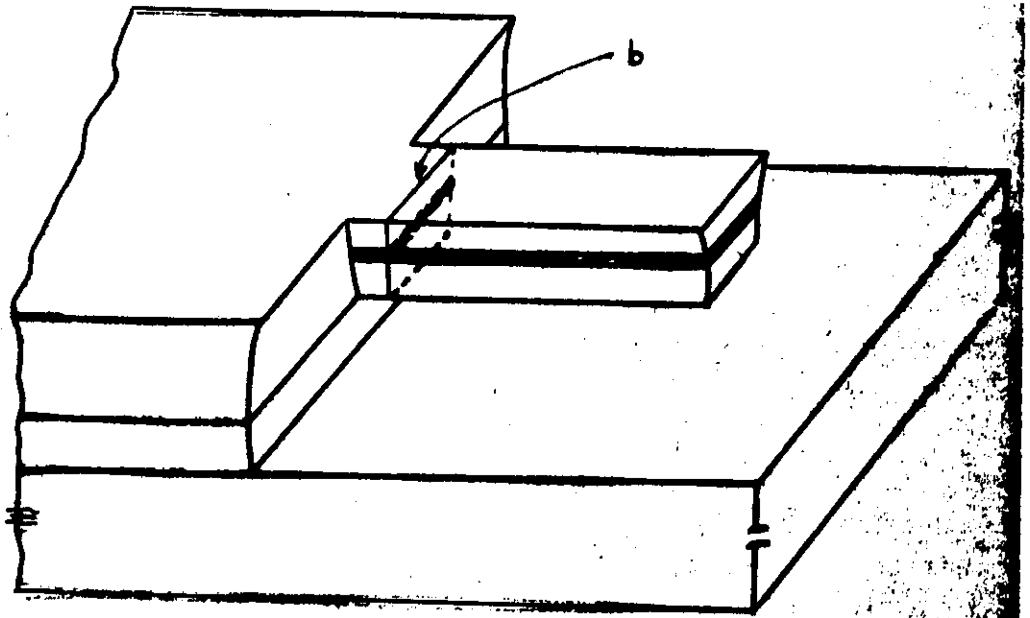
Fig. 5. Inert ion beam milling system. Samples may be tilted and/or rotated w the incident ion beam.

LASER CON MONITOR INTEGRATO





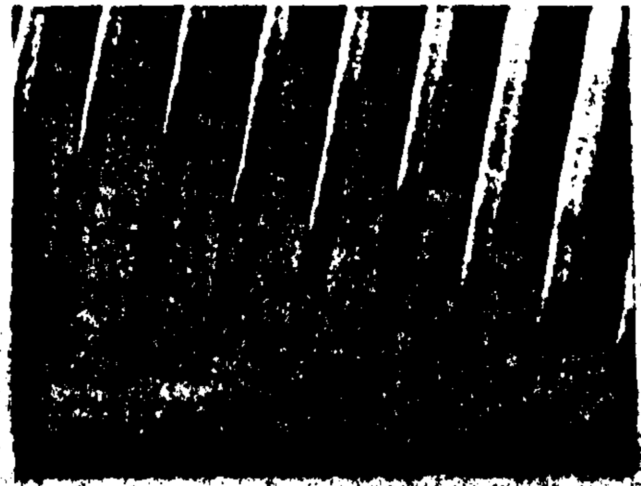
MICROCLEAVED - FACET - MIRROR INTEGRATED LASERS



a) AFTER SELECTIVE ETCHING A CANTILEVER STRUCTURE IS DEFINED

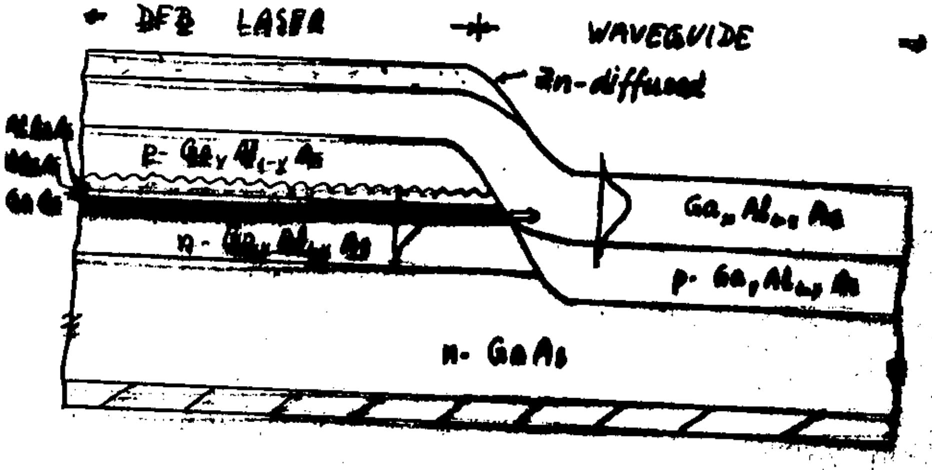
b) AFTER ULTRASONIC PROCESSING A SHORT, WELL-CLEAVED PROTRUDING MIRROR IS LEFT

HOLOGRAPHIC GRATINGS EXPOSED IN PHOTORESIST

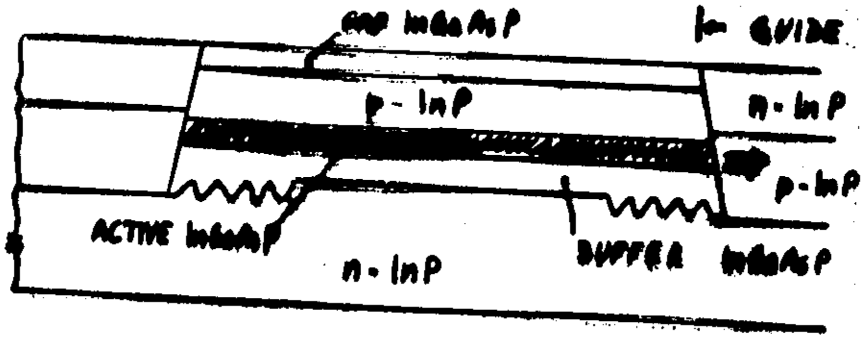


INTEGRATED LASERS

STRUCTURES FOR EFFICIENT COUPLING TO LOW-LOSS WAVEGUIDES



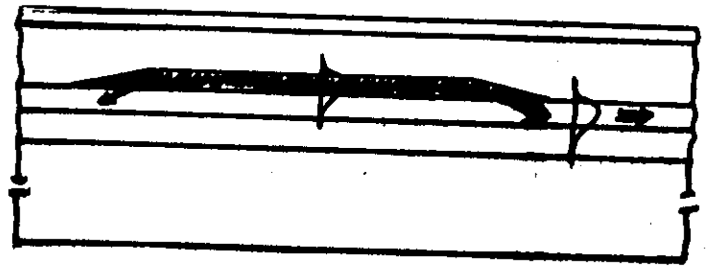
a) INTEGRATED DFB LASER + GUIDE, DIRECT COUPLING



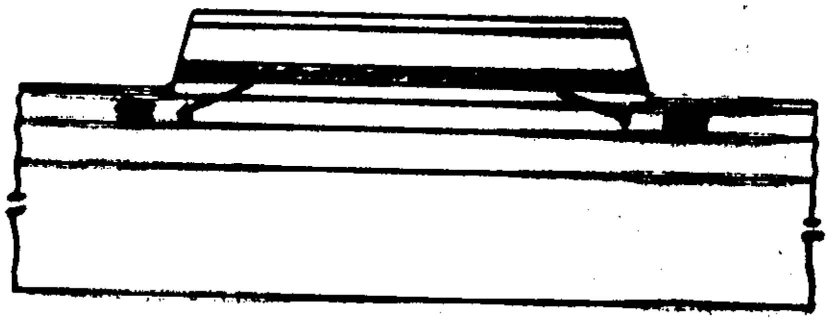
b) INTEGRATED DBR LASER + GUIDE, DIRECT COUPLING

INTEGRATED LASERS

STRUCTURES FOR EFFICIENT COUPLING TO LOW-LOSS WAVEGUIDES



c) LASER TAPER-COUPLED TO THE GUIDE



d) LASER EVANESCENT-COUPLED TO THE GUIDE

INTEGRATED OPTICAL AMPLIFIERS

THE FUNDAMENTAL STRUCTURE IS SIMILAR TO AN INTEGRATED LASER

TWO MAIN CLASSES OF AMPLIFIERS :

- RESONANT AMPLIFIERS
- TRAVELLING-WAVE (TW) AMPLIFIERS

REQUIREMENTS

RESONANT TYPE : MIRROR REFLECTIVITY 1 – 5%

TW TYPE : " " < 0.1%

STRUCTURES AND RELATIVE FEATURES

RESONANT: REDUCED REFLECTIVITY

- COATED FACETS
- SHALLOW GRATING DFB OR DBR
- LOW Δn TO BUTT-COUPLED GUIDE

} LOW NOISE, LOW GAIN, SELECTIVE ([illegible]

TW : STRONGLY REDUCED REFLECTIVITY

- HIGH PERFORMANCE AR COATING
- EMBEDDED STRUCTURE WITH

} HIGH GAIN, HIGH NOISE

INTEGRATED OPTICAL DETECTORS

- MANY STRUCTURES COMPATIBLE WITH INPUT FROM WAVEGUIDE
- MUCH LESS CRITICAL PROBLEMS THAN FOR SOURCE INTEGRATION
- SUITABLE MATERIALS : SILICON (FOR $\lambda < 1\,\mu m$)
InGaAs/InP (FOR 1.3 – 1.6 μm)
- GENERAL FEATURES :
  - HIGH BANDWIDT / LOW SIZE (SEVERAL GHz)
  - HIGH INTERNAL QUANTUM EFFICIENCY ($\eta \approx 100\%$)
  - EASY INTEGRATION WITH ELECTRONICS (SI-BASED)
  - DETECTORS CAN BE MADE ON PASSIVE MATERIALS (E.G. GLASS) BY USE OF LOCAL AMORPHOUS SI DEPOSITION

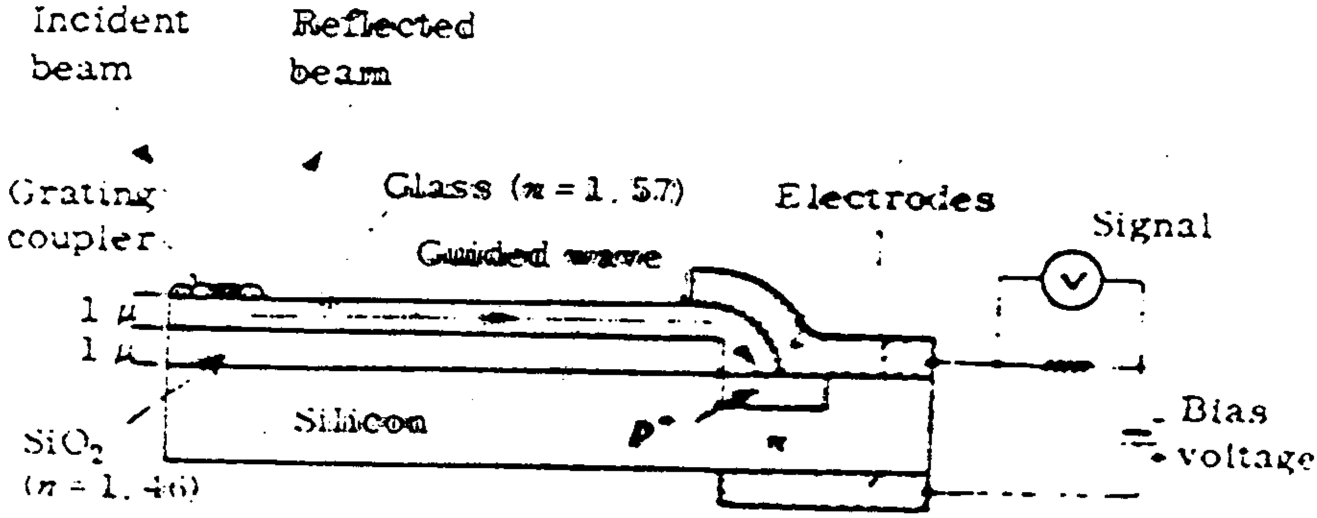
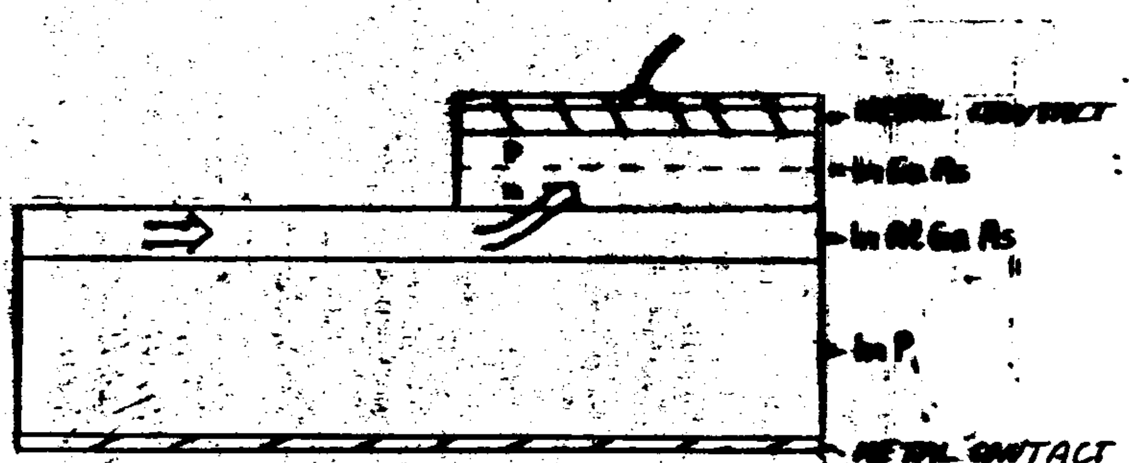
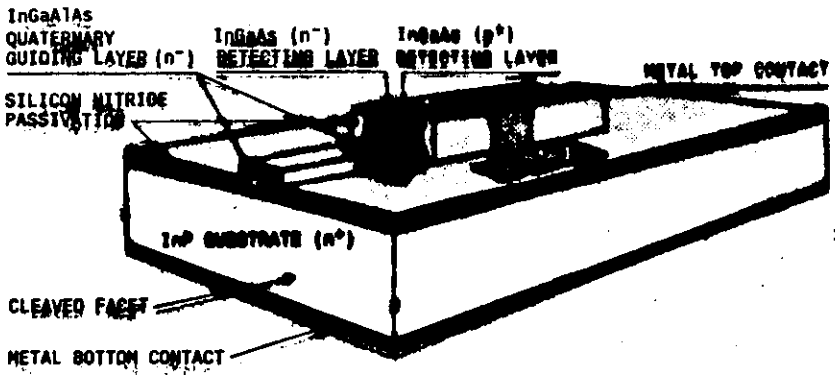


FIG. 1. Opto-electronically integrated photodetector schematic.



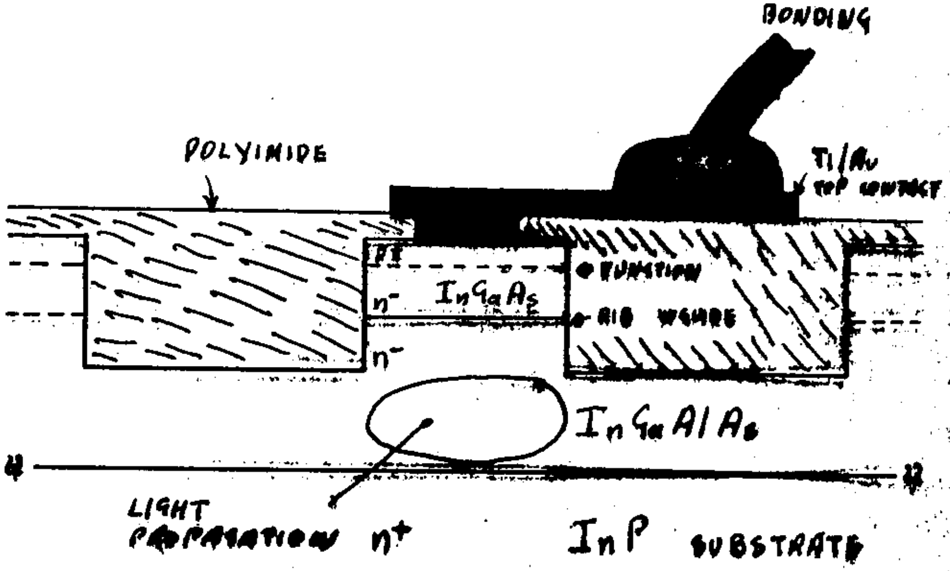
SCHEMATIC STRUCTURE OF ACTUAL
INTEGRATED PHOTODETECTOR
FOR 1.3-1.5 μm RANGE



HIGH "QUANTUM EFFICIENCY" INTEGRATED WGUIDE - PDs

$\eta_{int} \sim 80-100\%$ $\lambda = 1.55\ \mu m$

HIGH BANDWIDTH InGaAlAs INTEGRATED PHOTODIODES - SCHEMATIC CROSS SECTION



Au-Sn BOTTOM CONTACT

DIODE LENGTH: 200, 300, 400 µm
DIODE WIDTH: 10, 15, [illegible], [illegible] µm
InGaAs THICKNESS: [illegible] µm ($p^+ + n^-$)
InGaAlAs AND WIDTH: 10, [illegible], [illegible] µm
CONTACT PAD AREA: 50 × 50 µm²

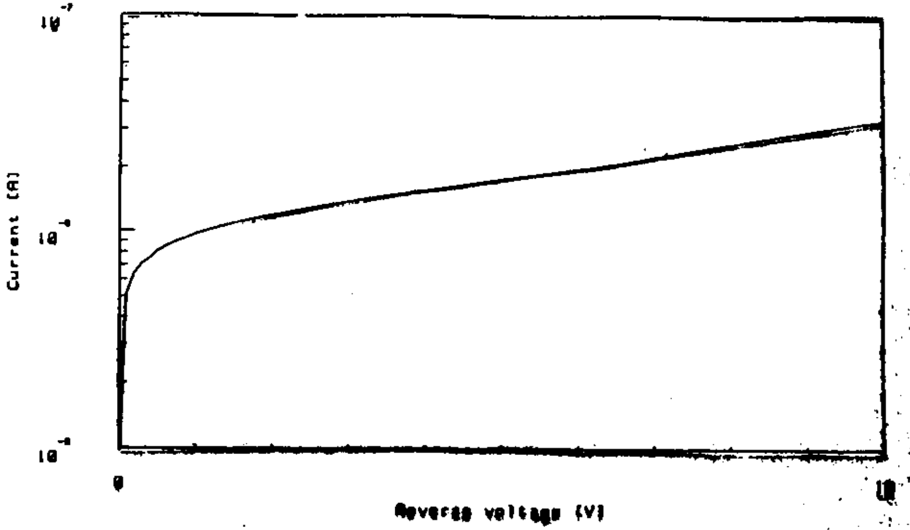


Fig. 9 : Reverse I/V characteristic of a high-speed device.

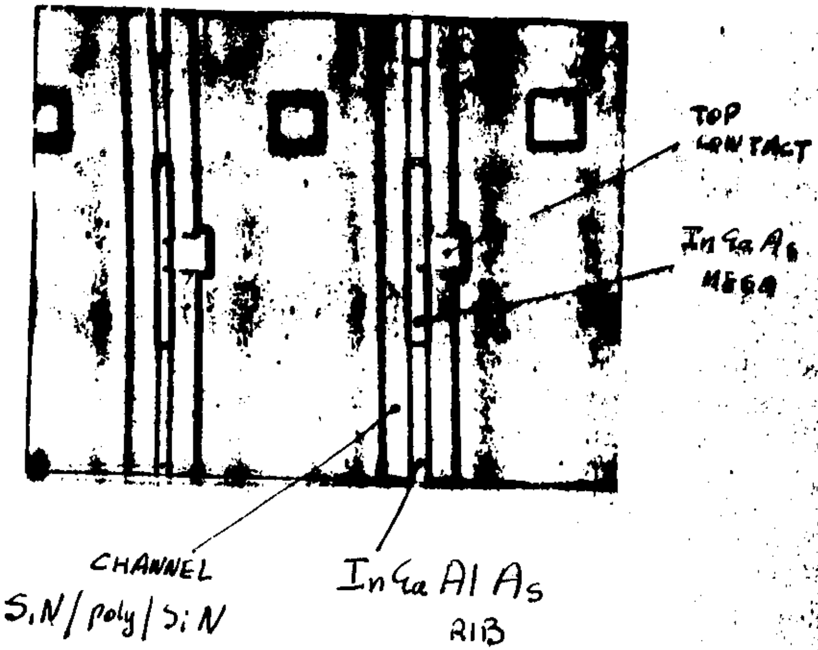
Fig. 10 : Optical micrograph of a high-speed device

$C(V=0) < 0.5$ pF

typical: $0.2 \sim 0.35$ pF

$\Delta f\,(\text{intrinsic}) = 1/\pi RC = 18 \sim 30$ GHz

$R = 50\,\Omega$



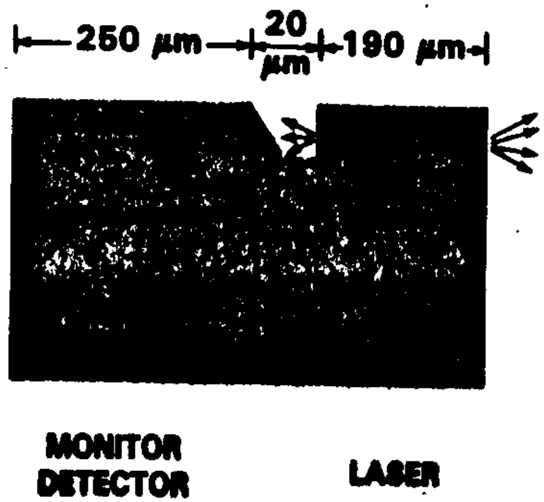
MULTIFUNCTIONAL DEVICES

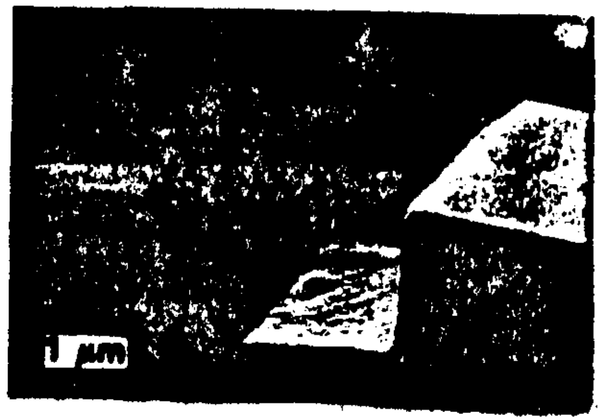
OPTICAL INTEGRATION ALLOWS FABRICATION ON A SINGLE CHIP OF COMPONENTS AND DEVICES FOR DIFFERENT FUNCTIONS:

EXAMPLES:

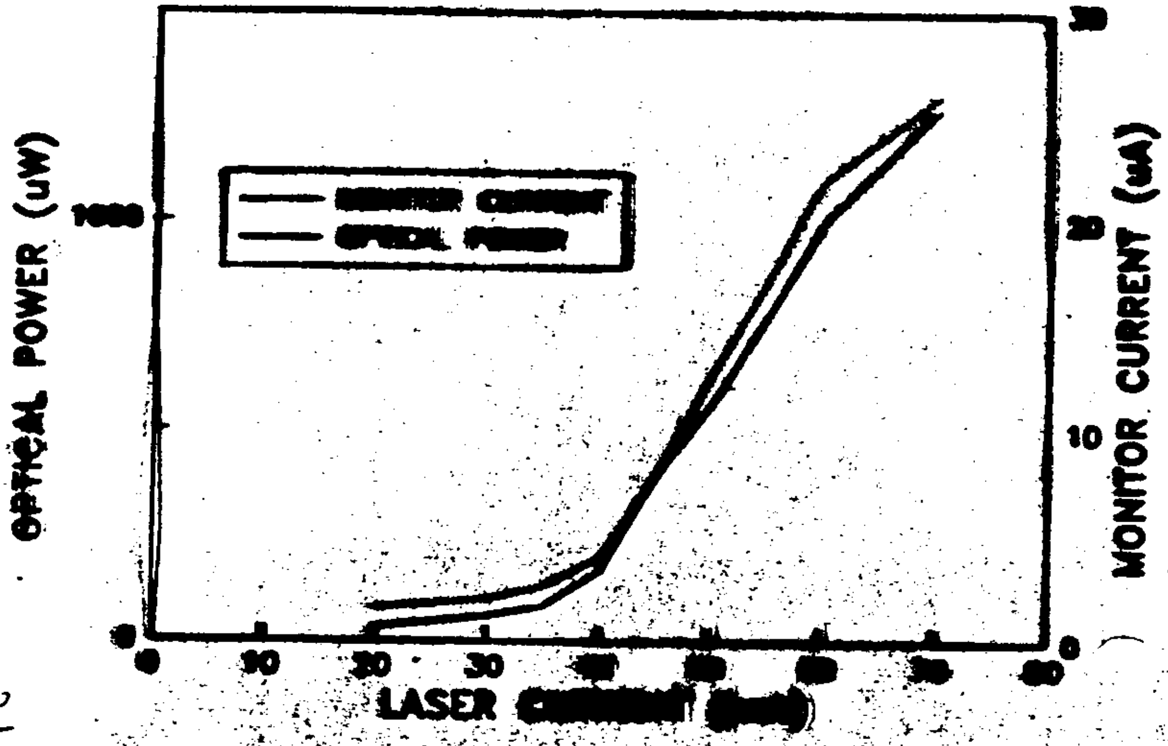
- LASER SOURCE + MONITORING DETECTOR
- LASER + SEPARATED MODULATOR (ν, φ, E)
- MULTIPLE LASERS WITH DIFFERENT λ
- MULTICAVITY LASERS
- LASERS + MULTIPLEXER
- DEMULTIPLEXER + DETECTORS
- POLARIZATION TRANSFORMERS + SPLITTERS
- MIXERS, COUPLERS, FILTERS + SOURCES + DETECTORS
- ALL COMBINATIONS OF THE ABOVE COMPONENTS
  . . . .
- OPTICAL + ELECTRONIC COMPONENTS (FET, HJBT, ...)
- ARRAYS OF COMPONENTS
  . . . .

LASER CON MONITOR INTEGRATO





MUSHROOM LASER – MONITOR WITH RIBE FACET



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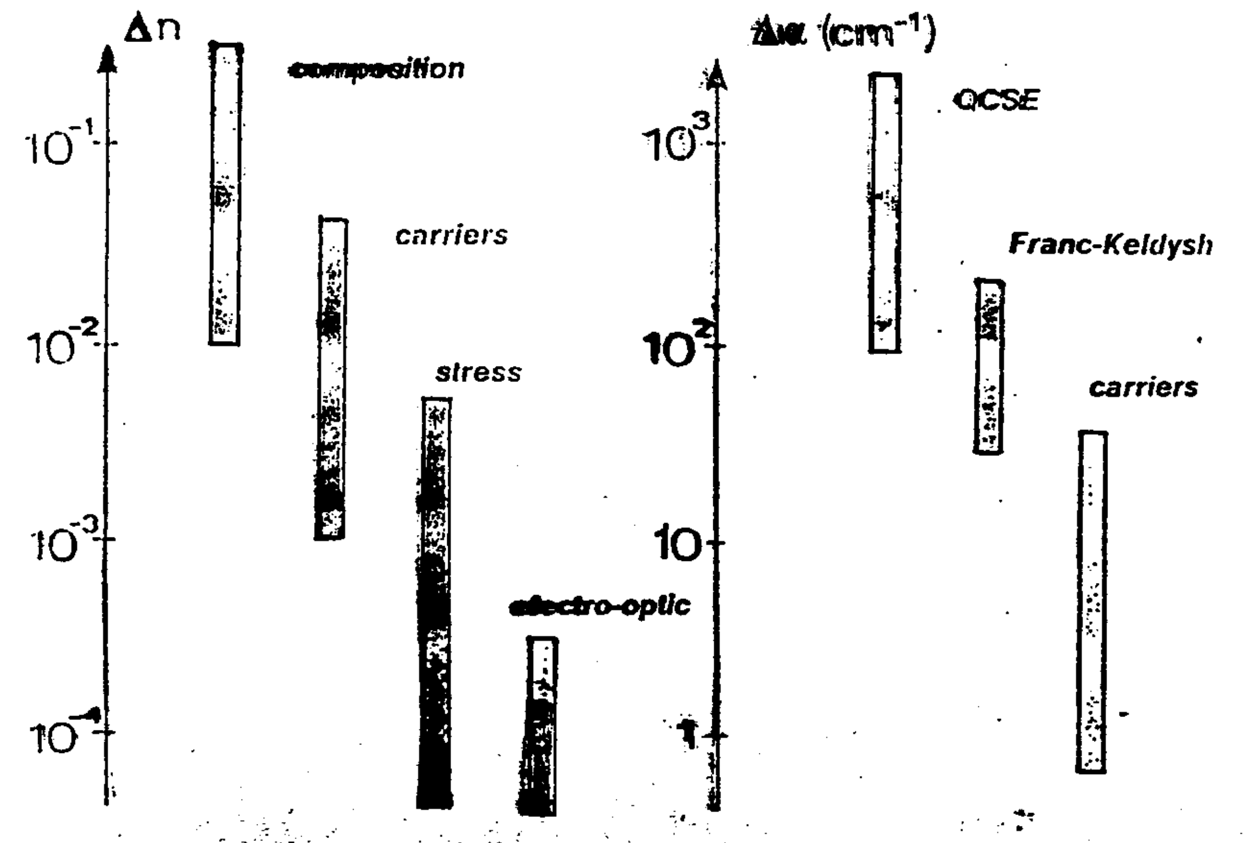
EFFECTS USABLE FOR TUNING AND MODULATION
IN INTEGRATED OPTICS ON III-V COMPOUNDS



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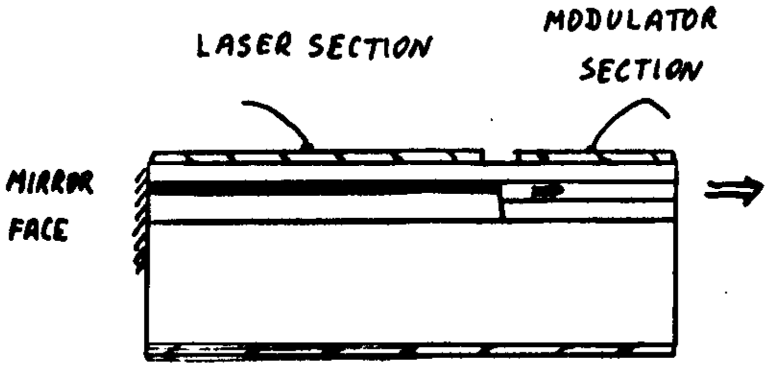


INTEGRATED LASER + MODULATOR :

a) Δn MODULATION IN MOD. SECTION :

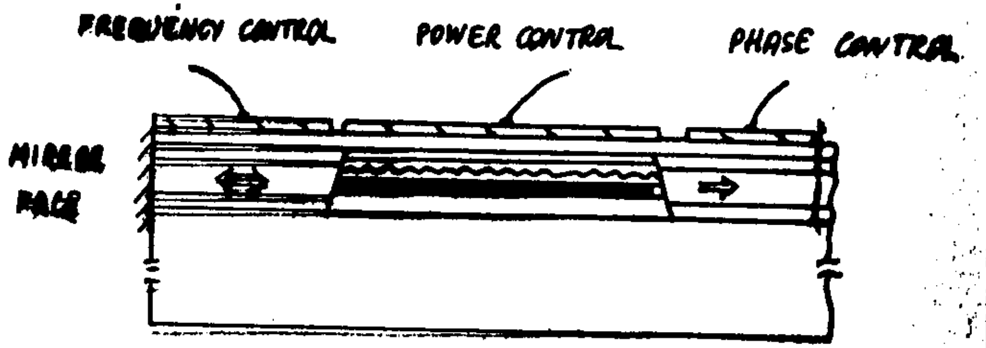
FREQUENCY MODULATED, CONSTANT AMPLITUDE

b) α MODULATION IN MOD. SECTION :

AMPLITUDE MODULATED SOURCE

ADVANTAGES :

- HIGHER SPECTRAL STABILITY THAN FOR DIRECTLY MODULATED LASER AT HIGH FREQUENCY
- FINE TUNING OF LASER FREQUENCY



INTEGRATED MULTICAVITY SOURCE WITH FULL SPECTRAL CONTROL

a) POWER CONTROL BY INJECTION CURRENT IN DFB LASER SECTION

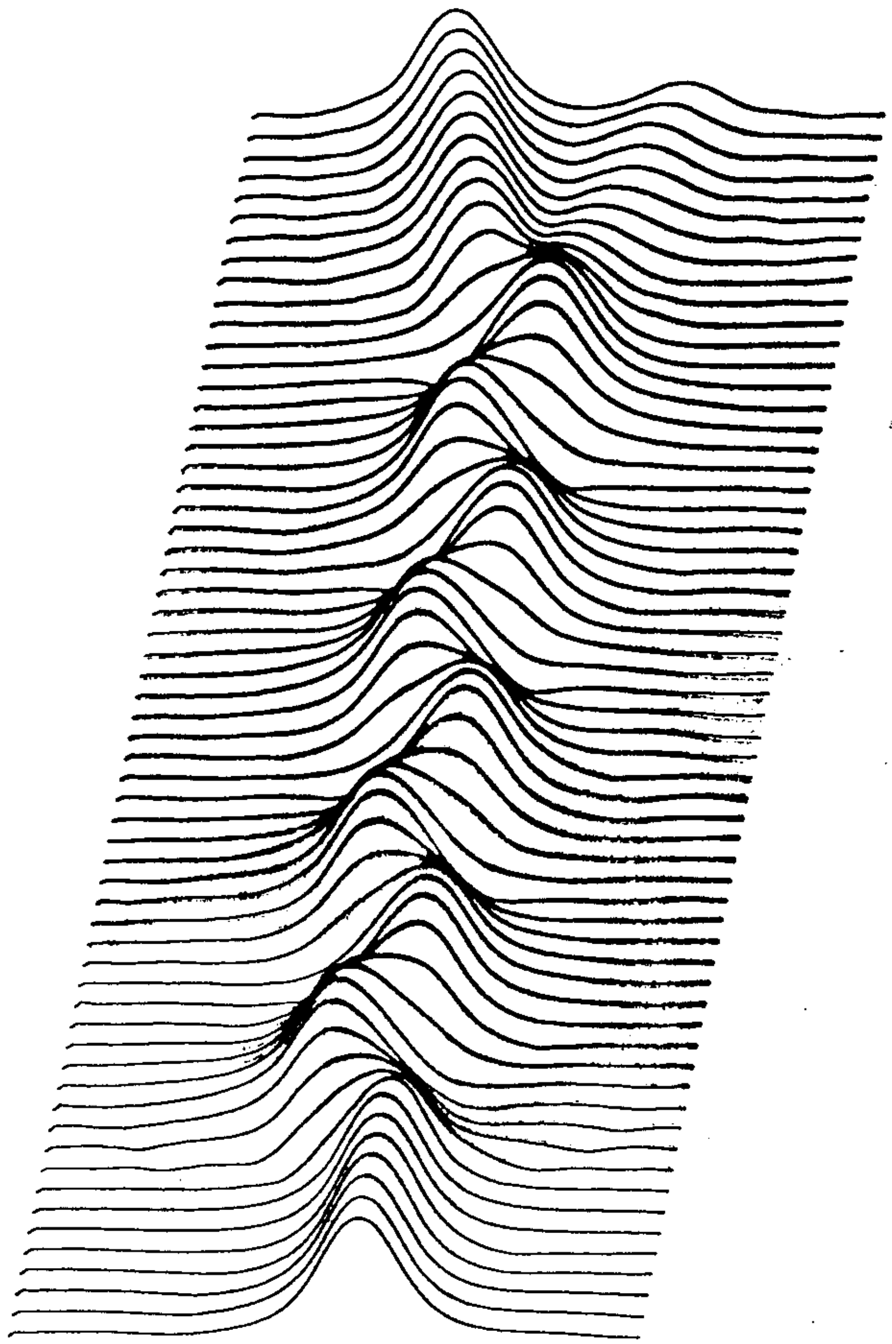
b) FREQUENCY CONTROL BY ELECTRO-OPTIC OR CARRIER-DENSITY CHANGE OF n IN THE COUPLED CAVITY SECTION

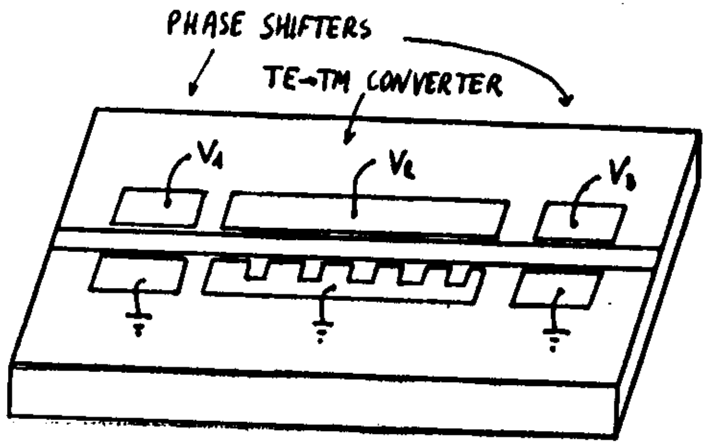
c) PHASE CONTROL BY SAME EFFECTS IN A SECTION OF THE OUTPUT GUIDE

ADVANTAGES :

- INDEPENDENT CONTROL OF ALL THE PARAMETERS OF THE OPTICAL WAVE
- HIGH OPERATION STABILITY IN THE REQUIRED MODE
- MUCH HIGHER SPECTRAL STABILITY THAN EQUIVALENT HYBRID STRUCTURES

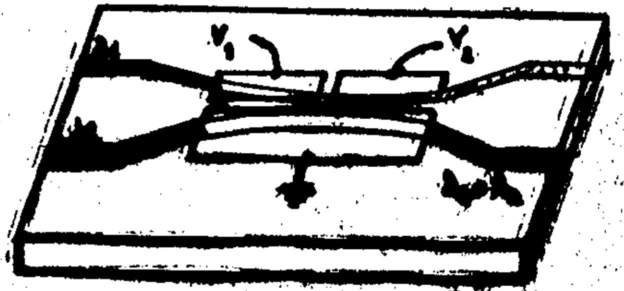
SIMULATION OF LIGHT PROPAGATION IN TWO-MODE-INTERFERENCE DEMULTIPLEXER





POLARIZATION CONVERTER

- PHASE SHIFTERS CHANGE RELATIVE PHASE BETWEEN TE AND TM WAVE BY $\underline{V_1}$ AND $\underline{V_3}$
- PERIODIC ELECTRODE TRANSFERS POWER BETWEEN TE AND TM WAVE WITH EFFICIENCY SET BY $\underline{V_2}$

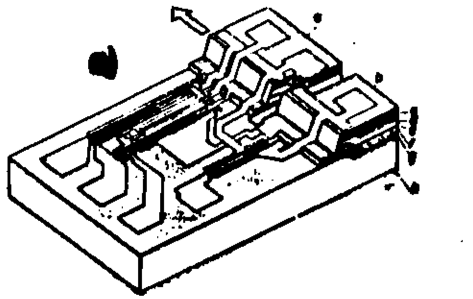


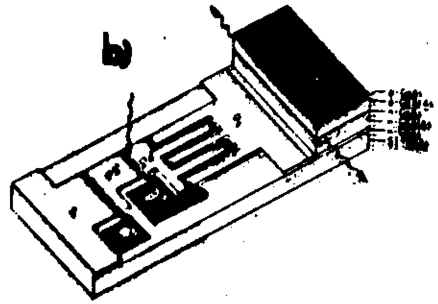
TUNABLE DIRECTIONAL COUPLER DEMULTIPLEXER

MULTICHANNEL DEMULTIPLEXER

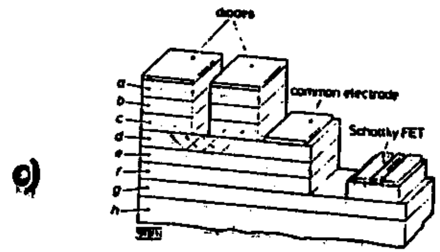
BRAGG FILTER DEMULTIPLEXED RECEIVER

EXAMPLES OF MONOLITHIC OPTOELECTRONIC INTEGRATION





a Laser. b Photomonitor. c GaAs. d GaAlAs. e GaAlAs (active layers) f GaAlAs. g GaAs (conductive layers) h Semi-insulating GaAs

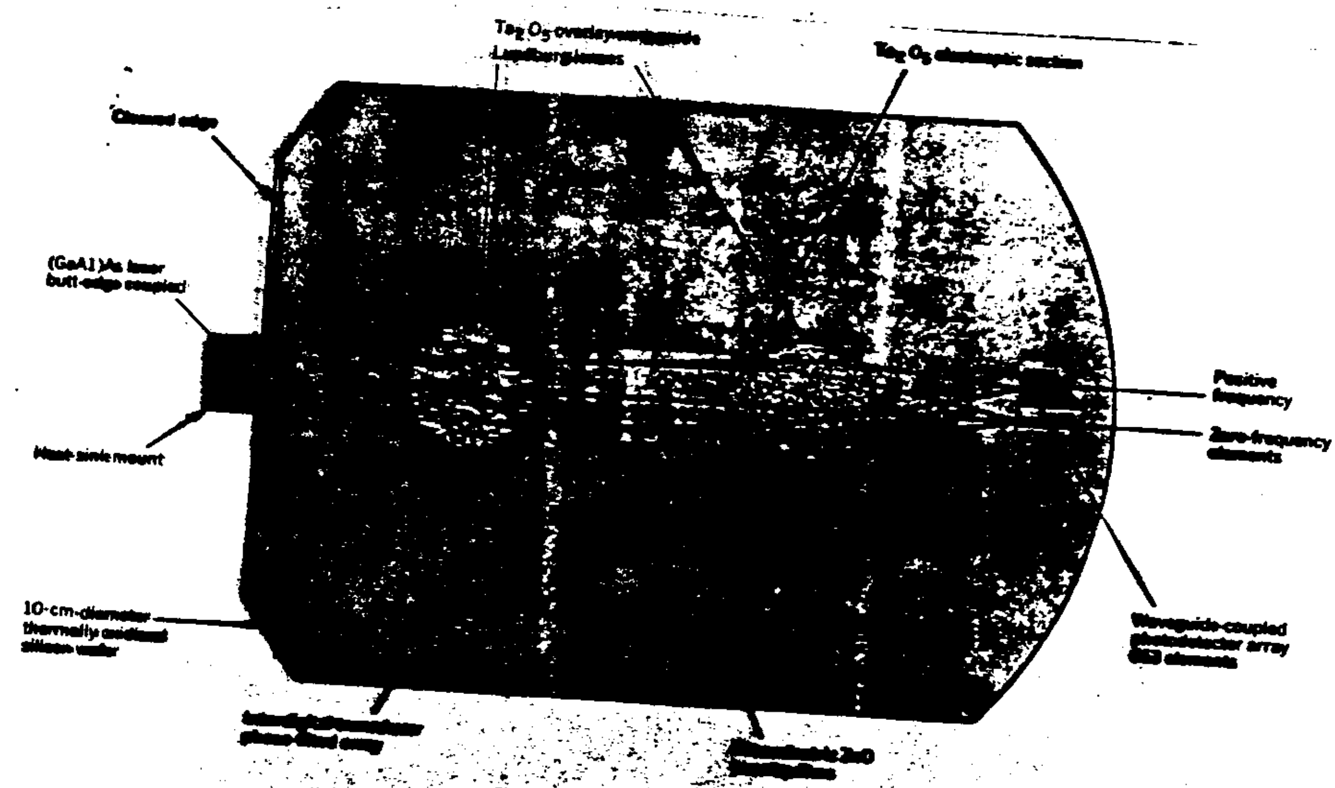


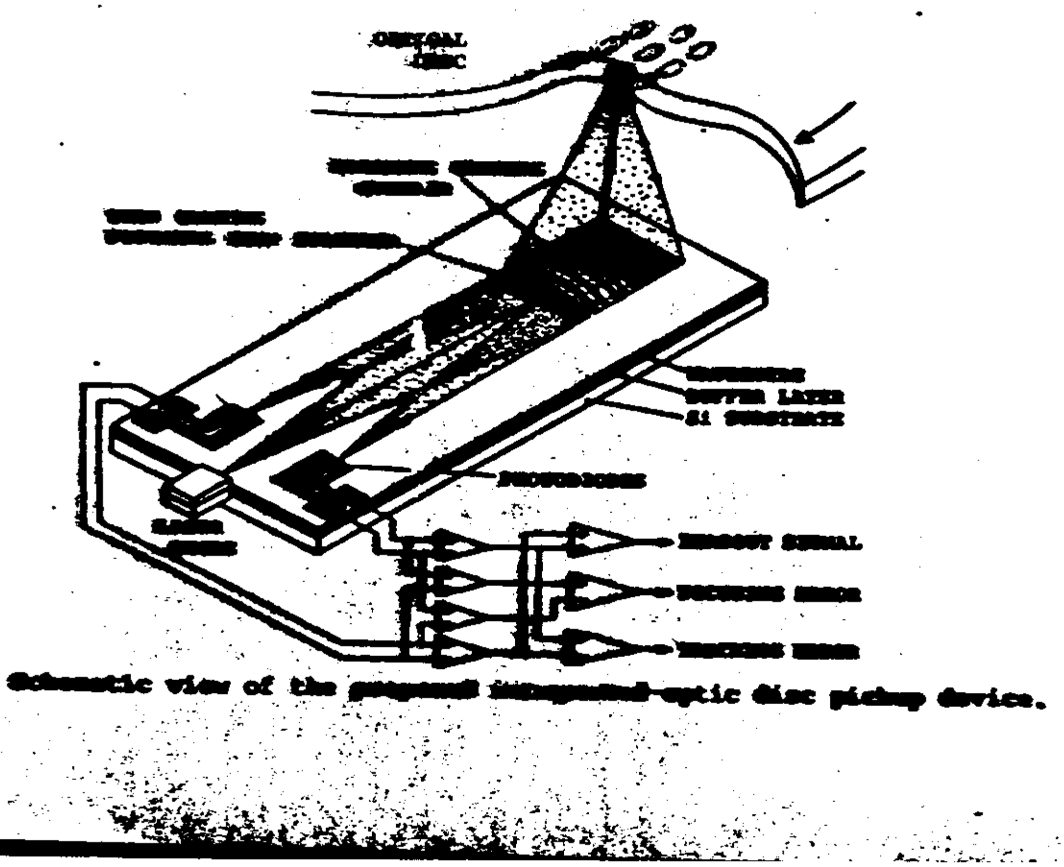
a p-GaAs cap layer
b p-Ga[illegible]Al[illegible]As upper guide
c n-GaAs active layer
d n-Ga[illegible]Al[illegible]As lower guide
e n-Ga[illegible]Al[illegible]As buffer layer
f n-GaAs FET layer

a) TRANSMITTER

b) REPEATER

c) MULTI-PURPOSE CIRCUIT





Schematic view of the proposed integrated-optic disc pickup device.