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WINTER COLLEGE ON
LASER PHYSICS: SEMICONDUCTOR LASERS
AND INTEGRATED OPTICS

(22 February - 11 March 1988)

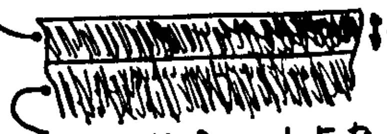
DEVICE FABRICATION PROCESSES FOR INTEGRATED OPTICS AND DEVICES IN PROTO-EXCHANGED LITHIUM NIBATE

R.M. De La Rue
Glasgow University
Glasgow, U.K.

Process steps for electrooptic stripe waveguide in titanium in-diffused lithium niobate

Part I: TITANIUM IN-DIFFUSION

(a)



Spin-on AZ 1350 (Shipley) positive photo-resist

(b)

Expose photoresist through partially light-blocking mask. Positive resist becomes soluble, where exposed to light, in the developer – i.e. pattern in PR is same as on mask. Then: Develop

(c)

Overcoat (evaporate) with titanium film (200Å — 1000Å) note separation of film in valleys between PR islands.

d)

Spray with acetone (plus ultrasonic agitation?) to LIFT-OFF most of titanium (except at windows in photoresist – which MUST be organically clean)

(e)

Heat up to 1000 - 1100°C for 6 - 18 hours. Diffuse titanium into $LiNbO_3$

Atmosphere: Flowing(?) O_2 (?), plus H_2O(?), plus lithium oxide vapour (e.g. from $LiNbO_3$ powder) to [illegible] Li_2O OUTDIFFUSION.

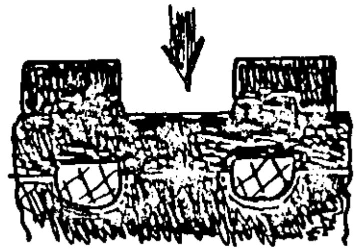
Part II: ELECTRODE DEFINITION

(f)

Evaporation deposition of aluminium film – followed by spin coating of photo[resist]

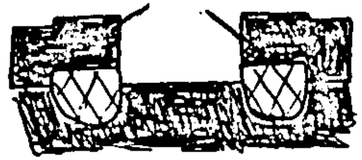
Note the bumps in Al-fil[m] above waveguide rid[ges]

(g)



Align electrode mask with visible ridges in aluminiu[m] film. Expose with UV li[ght]. Develop. Windows in mas[k] become windows in pho[to]resist.

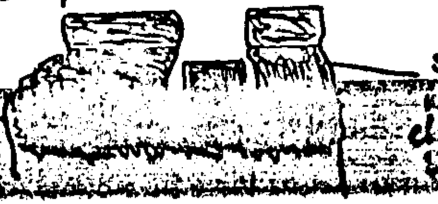
(h)



Remove unwanted alu[minium] by etching ('wet' or 'dr[y']) Spray with acetone to remove remaining pho[to]resist. Oxygen plasma ashing used for hardene[d] photoresist.

Normally, a buffer layer, e.g. of CVD Silica, is used to separate (optically) waveguide from metallic layer.

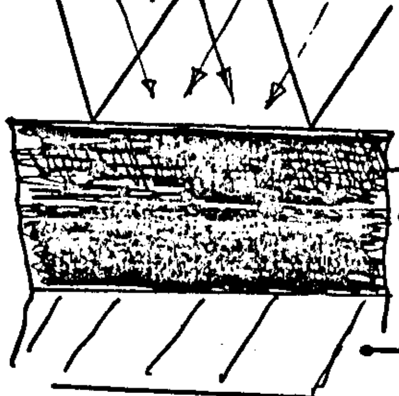
If thick (e.g. 2μm) metal electrode films are require[d] e.g. for devices working at, say, above 3GHz, the etching process may be replaced by lift-off. A 'chlorobenz[ene] soak' provides undercut sloping photoresist walls –



A further pos[sible] alternative [illegible]

Production of periodic mask structures for DFB lasers using holographic interference and X-ray replication

a)



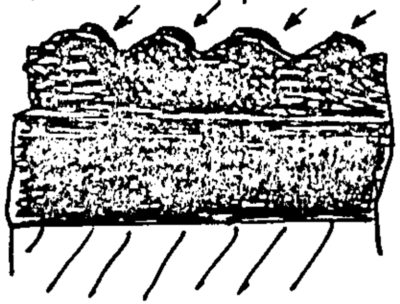
Interference pattern produced by intersecting argon laser beams. Exposes photoresist.

- photoresist
- Ni-Cr metallisation (~100 Å)
- polyimide layer
- glass substrate

b)

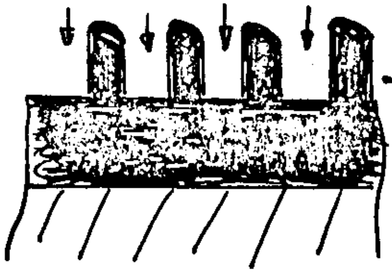
periodic ripple on surface, after development.

c)



Angled metal evaporation provides shadowed deposition

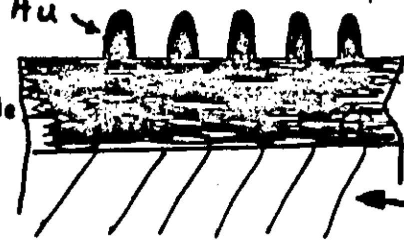
d)



Oxygen plasma etching (directionally anisotropic).

4:1 (or higher) aspect ratio photoresist columns

(e)



(~0.4 μm plus, high)

Evaporated gold deposition, plus lift-off.

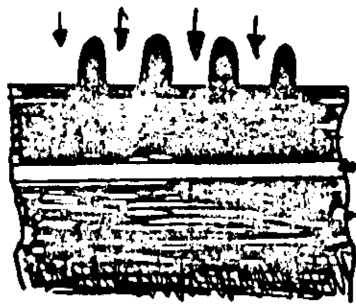
glass substrate

(f)

air/vacuum

Etch glass substrate away leaving high X-ray contrast metal pattern (Au) on flexible polyimide substrate (stretched over metal support ring).

(g)



- gap (small)
- X-ray resist
- GaAs, InP, or ternary/quaternary

X-ray exposure of resist-coated III-V semiconductor substrate.

(h)

Develop resist and dry etch - e.g. with SiC_4 or CH_4/H_2

The mask, consisting of thick Au pattern on polyimide substrate - on a metal ring support, is electrostatically chucked, in vacuo, onto the resist-coated substrate.

Devices

1) <u>Passive Bragg-grating beam-splitter</u> (Glasgow)

2) <u>Stripe-waveguide electrooptic frequency shifter</u> (Glasgow)

3) <u>Acoustooptic devices</u> (Korablev et al, Davis)

4) <u>Lenses</u>: chirp-grating, analogue Fresnel, simple (concave(inverse) and convex), lenslet arrays (Chang, Suhara, Yu, Tsai)

5) <u>Second Harmonic Generation (SHG)</u>: phase-matched planar (DeMicheli), stripe-guide leaky 'Cerenkov' (Taniuchi and Yamamoto)

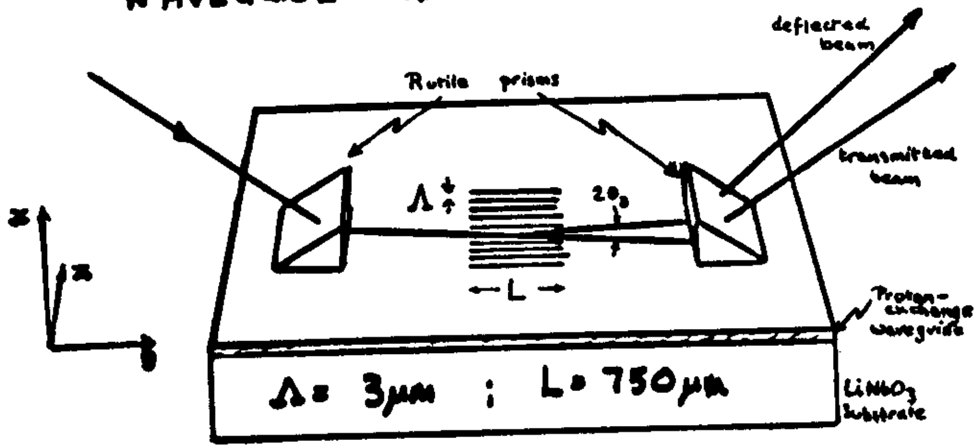
6) <u>Temperature Sensor:</u> 180° arc Mach-Zehnder (Haruna)

7) <u>Ring-resonator:</u> also temperature sensitive ! (Mahapatra)

8) <u>Waveguide Polarizer:</u> (Veselka and Bogert)

9) <u>etc</u>

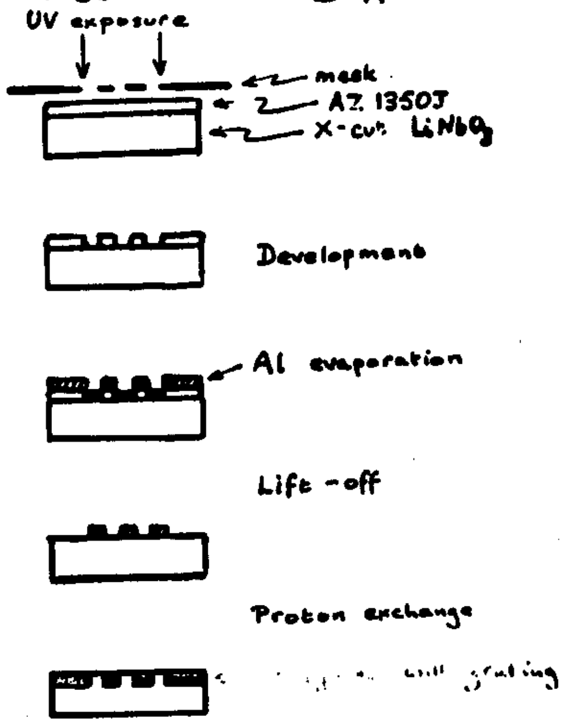
WAVEGUIDE BRAGG-DEFLECTION GRATING



PUN E.Y.B. et al 'Efficient waveguide Bragg-Deflection Grating on $LiNbO_3$' Electronics Lett. 18, pp. 740-741, 198

$\eta \approx 90\%$

FABRICATION PROCESS



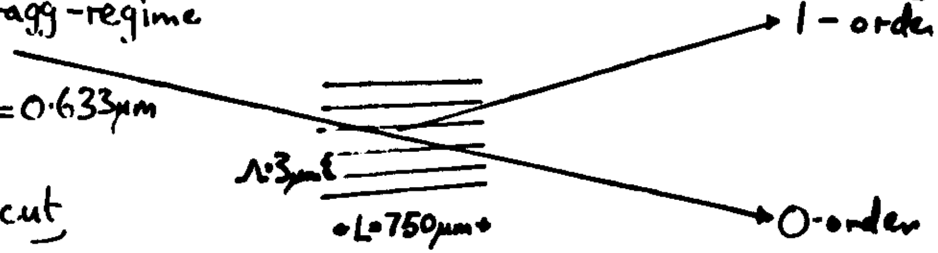
I. Proton-exchanged gratings - $LiNbO_3$

Pun, Wong, Andonovic', Layb[e] ... De La Rue

$T_e \simeq 170°C$, $t_e \simeq 90$ min

Single-litho-stage → grating + waveguide } → Aluminium Mask

Bragg-regime



Δn s.c.l., several 0 ⇌ 1 transfers over 750μm

Measured 90% into 1st order → 100% slightly {shorter / longer} L ?

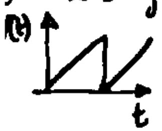
Submitted to Electronics Letters - 1st July 1981

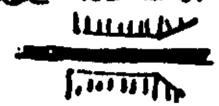
I Proton-exchanged Electrooptic serrodyne frequency-shifter

Manuscript in preparation + Performance ≥ as reported (STL now) ← Wo[ng], Wrig[ht], De La [Rue]

European IO Conf 1981, Asilomar IO Conf 1982 ← Ti

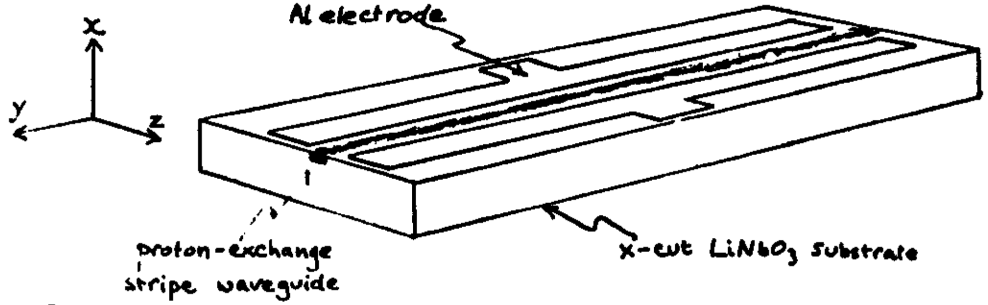
Strongly confined, single Al layer for w/g mask (but 2-stage litho for phase modulator) ← tapered-in electrodes (ideally)





Induced frequency shift / spectrum observed by heterodyne Mach-Zehnder (a-o Bragg cell in one arm) + HP electronic spectru[m] analyzer. ~8 to 10 Volts p-p - 2π phase-shift (~1 MHz)

Proton-exchange e-o device not stable under few Volts dc, - either polar[ity]



SCHEMATIC OF PROTON-EXCHANGE PHASE MODULATOR

Wong K.K. et al 'Electro-optic waveguide frequency translator in $LiNbO_3$ fabricated by proton-exchange'

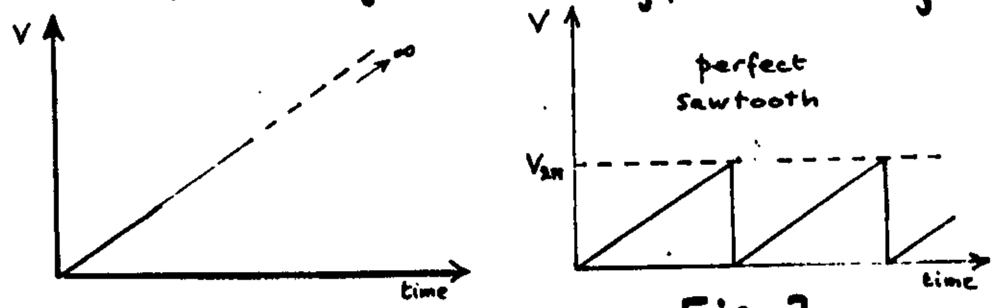
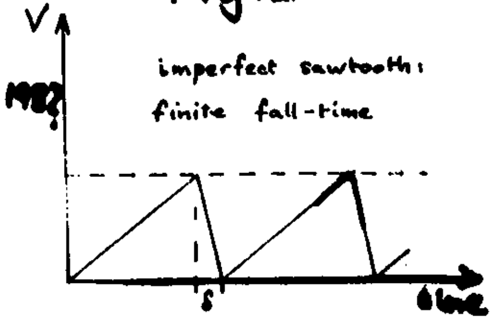


Fig. 2.

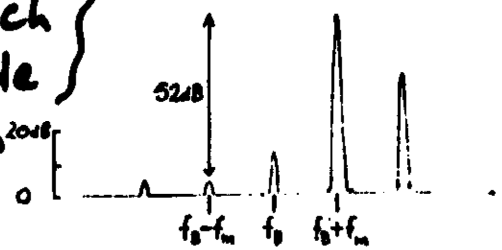
Phase modulator + linear ramp = frequency modulator

Optics Lett. 7, pp. 546-548, 1982

SERRODYNE DEVICE OPERATION



How much amplitude modulation ?



$f_B = 210$ MHz

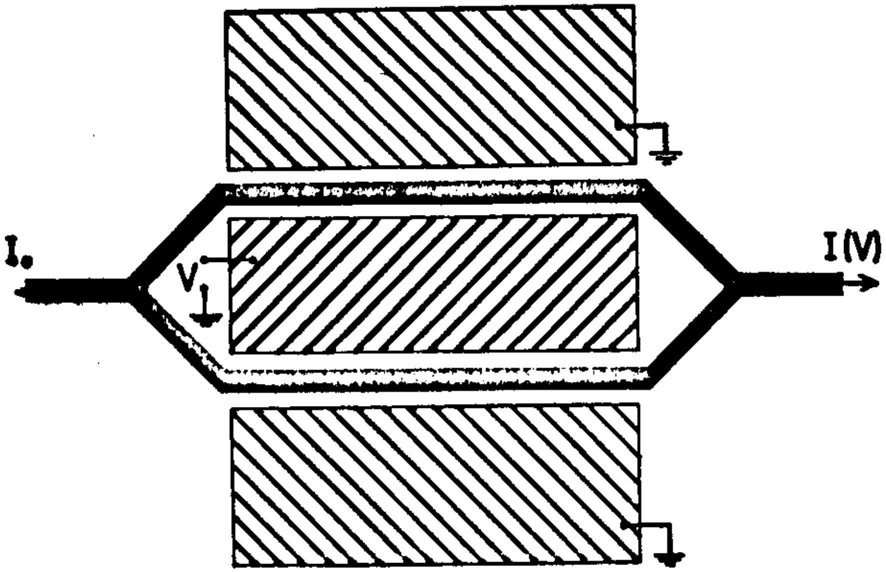
$f_m = 4.0$ MHz

SPECTRUM ASSOCIATED WITH UPSHIFT IN FREQUENCY

(Heterodyne MZ + Bragg cell)

Becker, R.A. "Comparison of Guided-wave Interferometric Modulators fabricated on $LiNbO_3$ via Ti Indiffusion and proton-exchange."

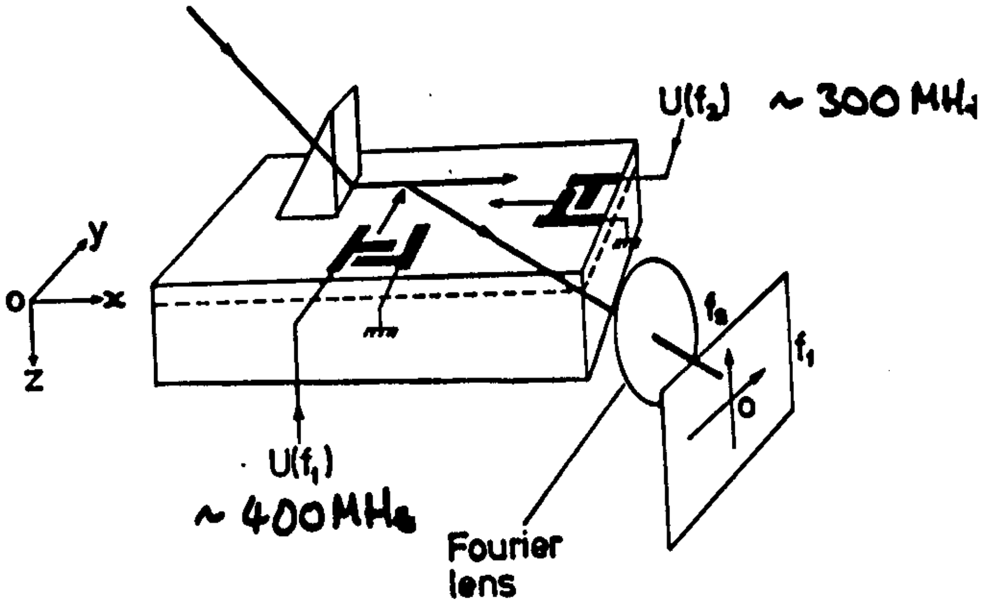
Appl. phys. lett. vol. 43, pp 131–133, 1983



Guided-wave electrooptic Mach-Zehnder interferometer.

See also: Becker R.A. 'Guided-wave optics in $LiNbO_3$: physical properties, devices and signal-processing systems' Proc SPIE Vol 517, pp 194–198 (1985)

Korablev, E.M., et al "Acoustooptic investigations of proton-exchanged waveguides." 1984 IEEE Workshop on integrated optical and Related Technologies Florence, Italy, Sept 10-11, 198[illegible] (Addendum)

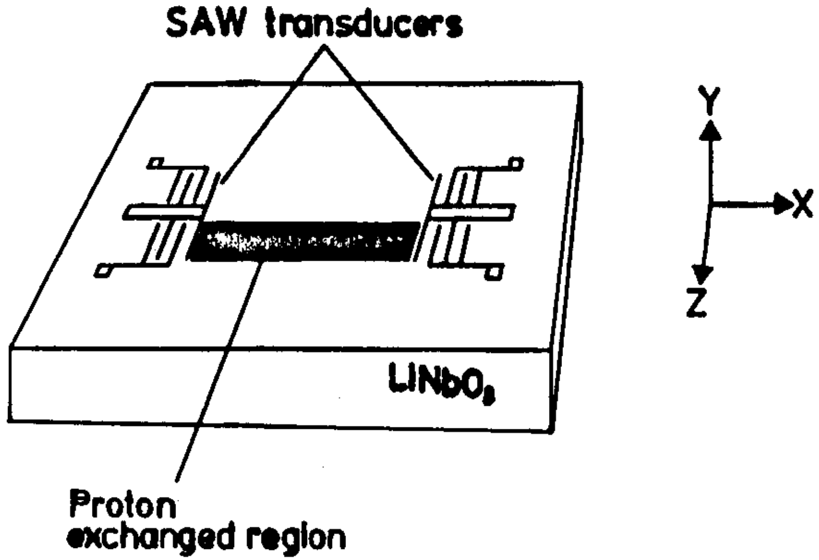


Also: Dawar A et al 'Surface acoustic wave-guided optical wave interaction in Y-cut $LiNbO_3$ annealed proton-exchanged waveguides', ibid

and

Davis R.L. 'Acousto-optic Bragg diffraction in proton-exchanged waveguides', Proc SPIE 517, pp 74-81 198[illegible]

Hinkov, V., et al Proc. 3rd Europe Conf. Integrated Optics, Berlin, pp. 169-173, 1985.



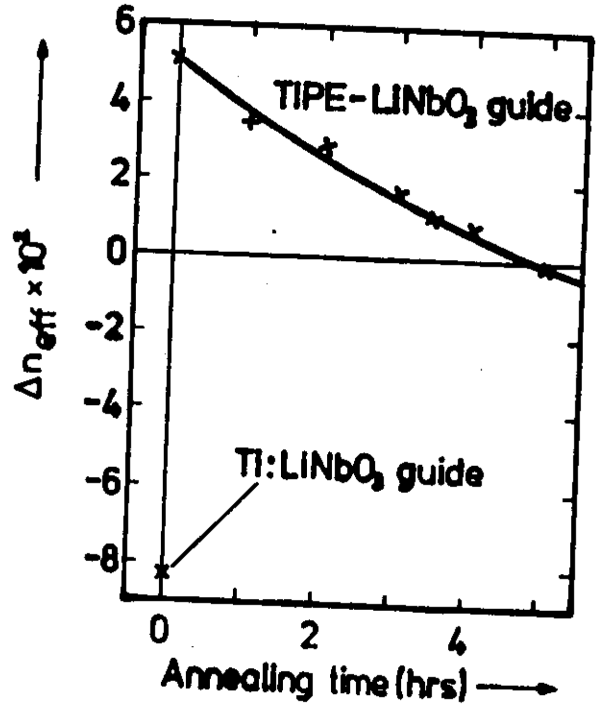
Schematical sample geometry of Ti-diffused/proton-exchanged waveguide for collinear acoustooptic mode conversion.

f_a = 85 MHz. 5% conversion at 4 W drive.

Acoustic waveguiding $\Delta v/v \to 20\%$

Hinkov, V., et al "Low frequency collinear acoustooptic TM_0-TE_0 mode conversion and single sideband modulation in proton-exchanged $LiNbO_3$ optical waveguides."

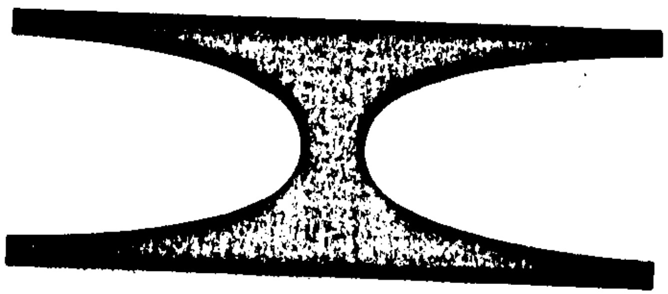
Proc. 3rd Europe Conf. Integrated Optics Berlin pp. 169-173, 1985.



Birefringence of the fundamental modes of a Ti-diffused/proton-exchanged (TIPE) optical waveguide and of a Ti:LiNbO$_3$ guide as function of the the annealing time (λ = 0.63μm)

Yu, Z.D., "Waveguide optical planar lenses in $LiNbO_3$ - theory and experiments,"

Opt. Commun., vol. 47, pp. 248-250, 1983.



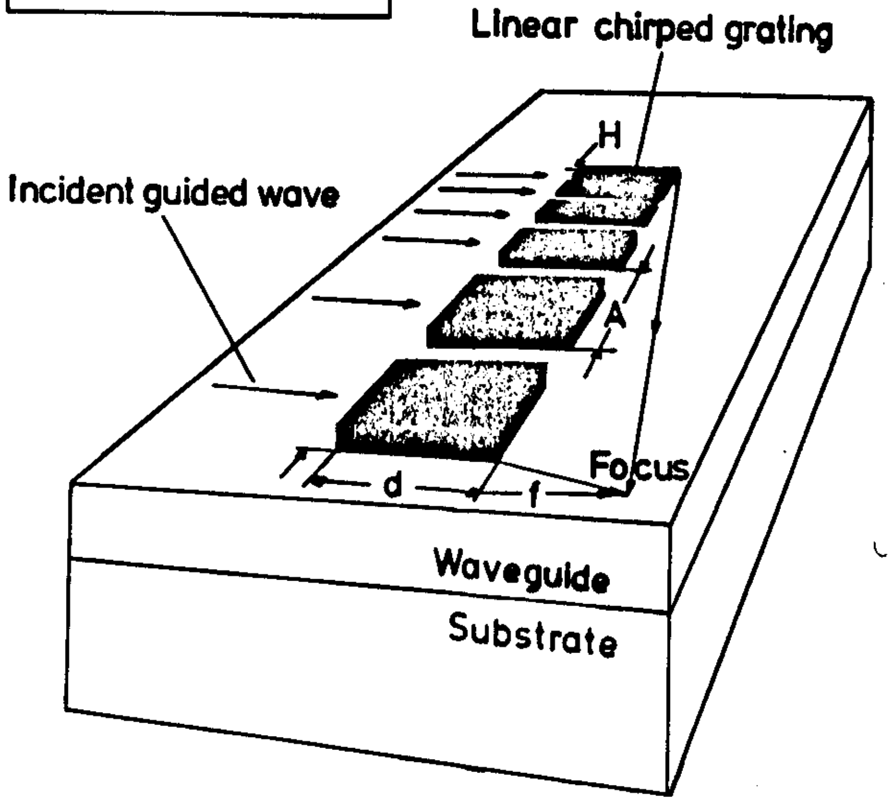
Mask of F=15mm dual lens.
White is the TIPE region, blue is the TI region.

See also: D.Y. Zang (= Z.D. Yu) et al 'Single-mode waveguide microlenses and microlens arrays fabrication in $LiNbO_3$ using titanium indiffused proton exchange technique' APL, 46, pp. 703-705, 15 April 1985.
short focal length structures.

Warren, C, et al "Double ion exchanged chirp grating lens in lithium niobate waveguides."

Appl. phys. lett. 43(5), 1983
pp 424-426

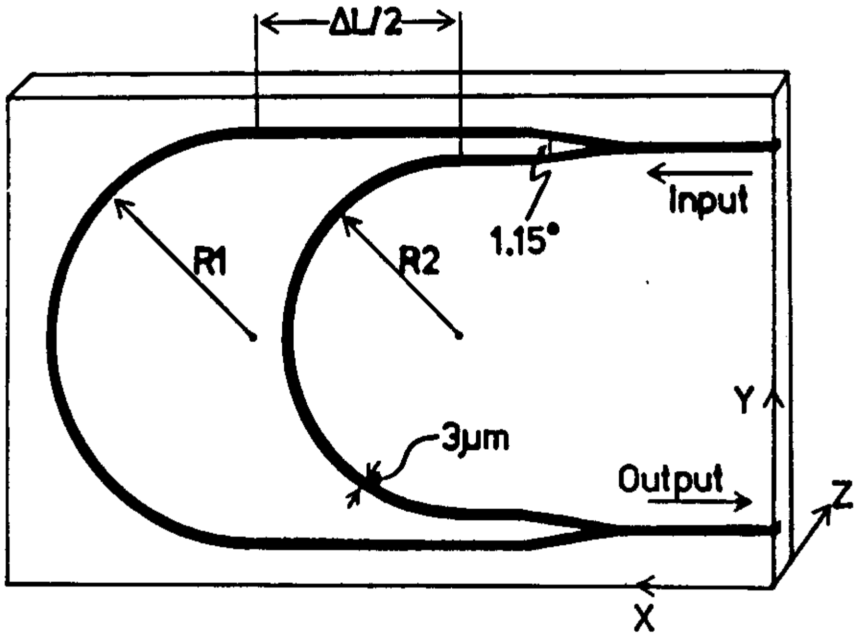
Typical dimensions of a grating lens:
d = 15 - 400μm
A = 1-20μm
H = 1 to several mm
f = 5-30mm



Chirped grating lens structure and the typical ranges of the design parameters used.

Haruna, M., et al "Optical π-arc waveguide interferometer in proton-exchanged $LiNbO_3$ for temperature sensing

Applied Optics 24, pp. 2483-2484, 15th Aug, 1985.



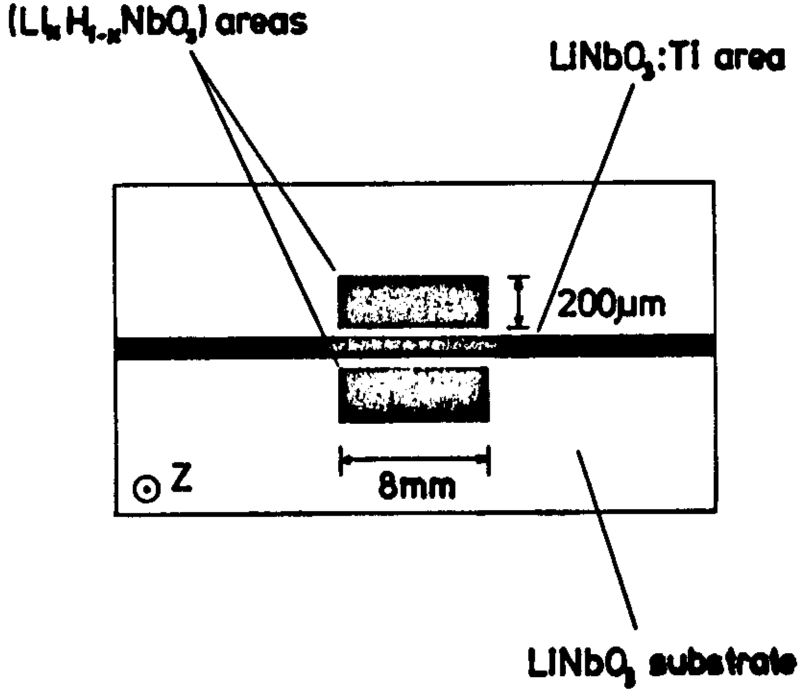
$R_1 \approx R_2 \approx 5mm$

$\Delta L = 30\,mm \rightarrow T_\pi = 0{\cdot}3\,°C$

Ring Resonators → Mahapatra and Robinson → this Conf

Papuchon, M. and Vatoux, S. "Integrated optical polariser on $LiNbO_3$: Ti channel waveguides using proton exchange"

Electron. Lett., vol. 19 pp. 612-613, 1983.



Schematic view of the polariser structure