Fabrication Methods of Lithium Niobate Optical Modulators

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Outline

- Description of Optical Modulators
- Fabrication Types
- Conclusion

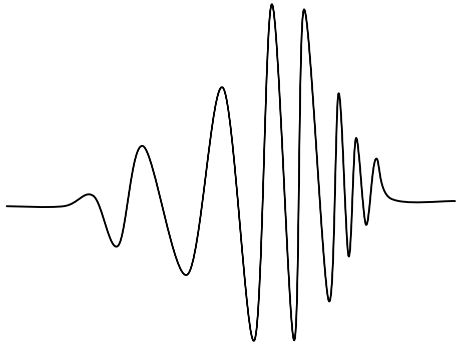
Description of Optical Modulators

- Direct Modulation - cheap, simple design, chirped pulses

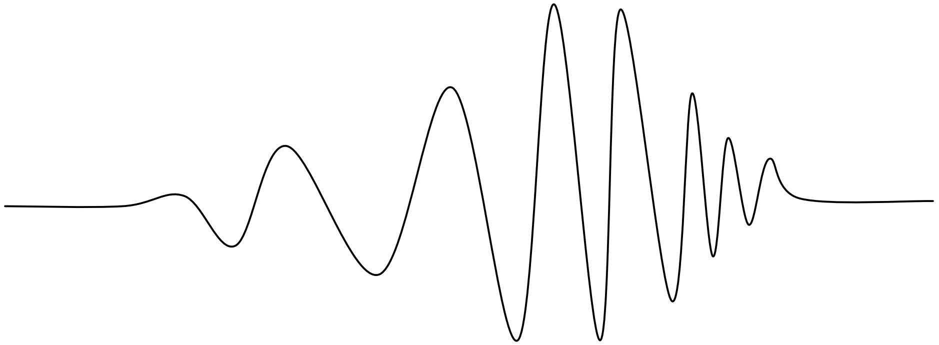
- External Modulation – more expensive, excellent chirp performance
  - Electro-absorption Semiconductor
  - Lithium Niobate Modulator

Chirp

- Frequency of launched pulse changes with time



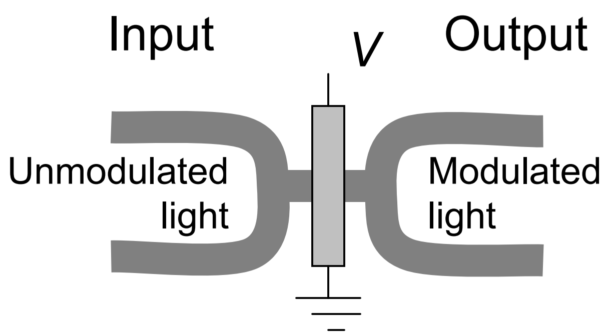
Chirp



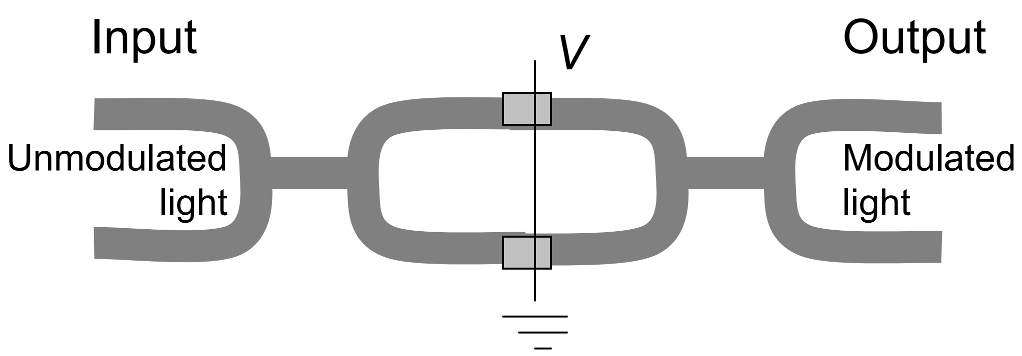
Dispersion

Lithium Niobate Modulators [1]

- Directional Coupler



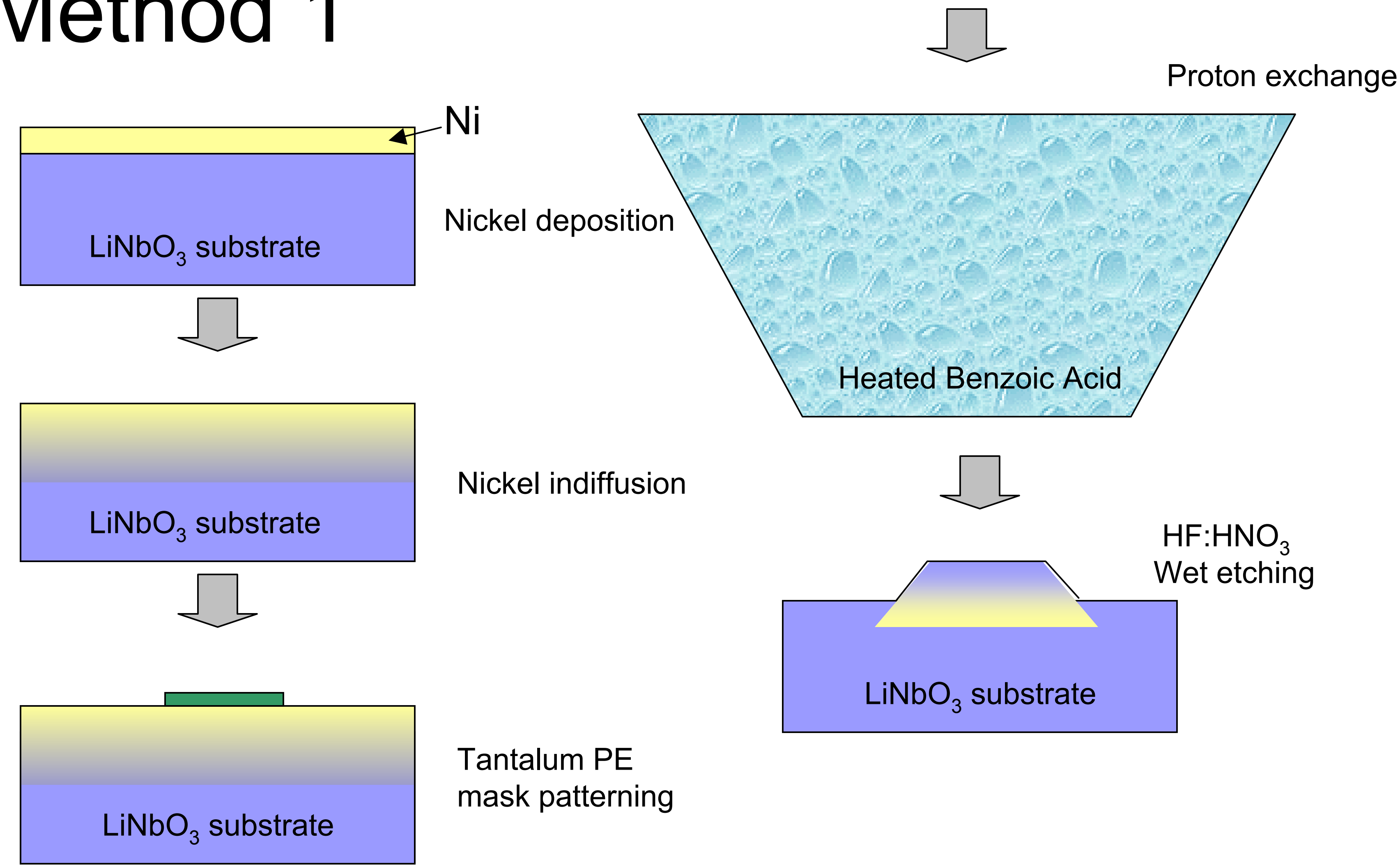
- Mach-Zender Interferometer



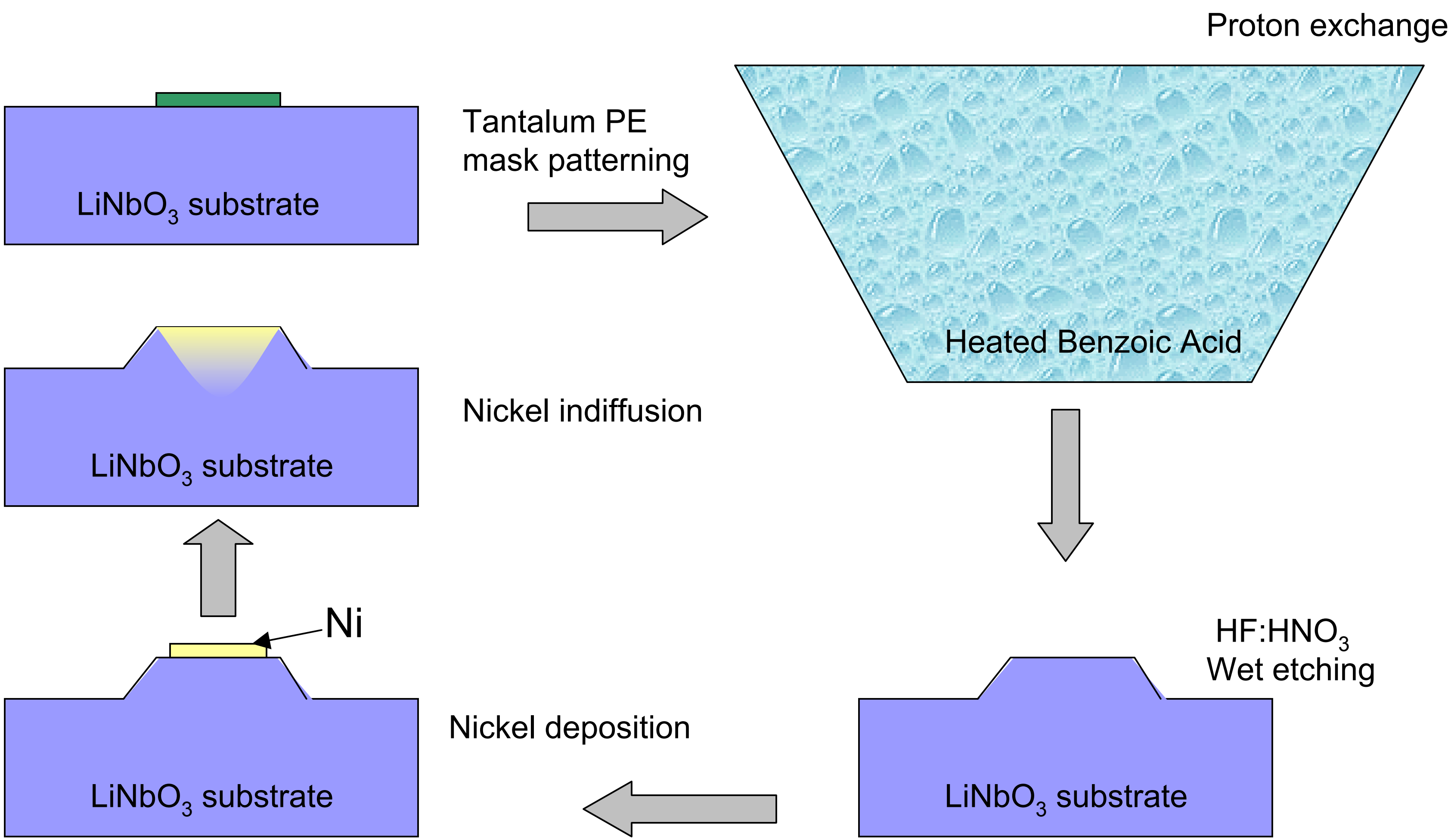
Fabrication Types

- Z-Cut
- X-Cut
- Y-Cut

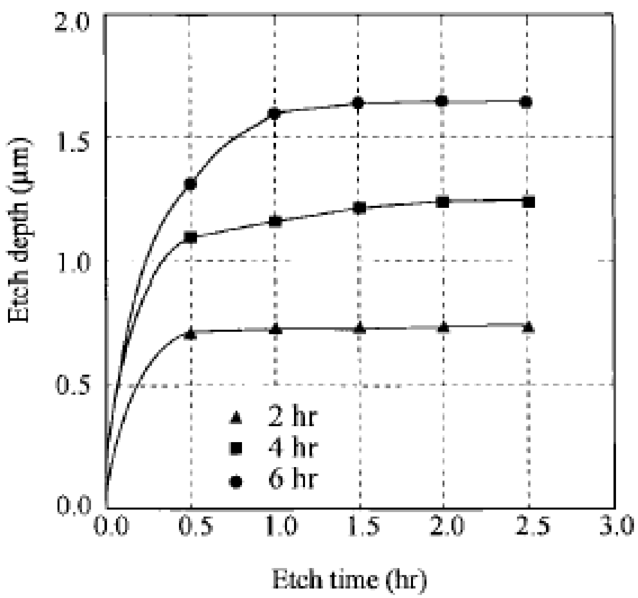
Z-cut $LiNbO_3$ Ridge Waveguide Method 1



Z-cut $LiNbO_3$ Ridge Waveguide Method 2



Experimental Results [2]



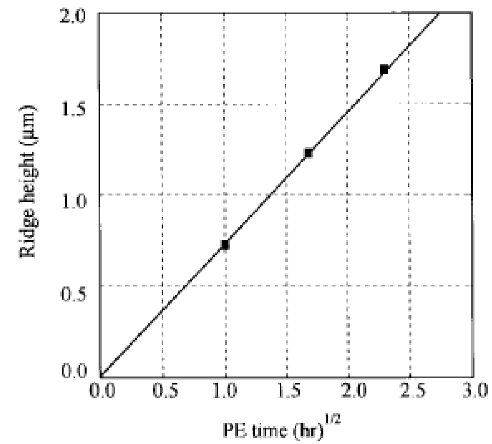


Fig. 3. Ridge height versus PE time for ridge waveguides in z-cut $LiNbO_3$. The proton exchange is done in benzoic acid at 240 °C.

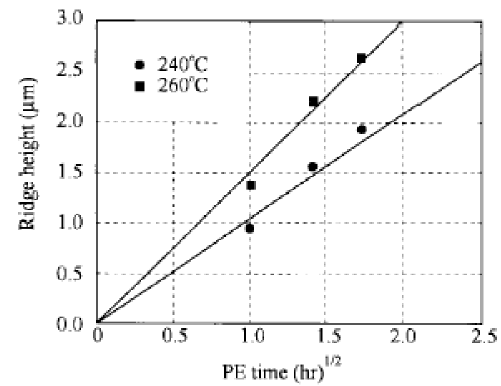
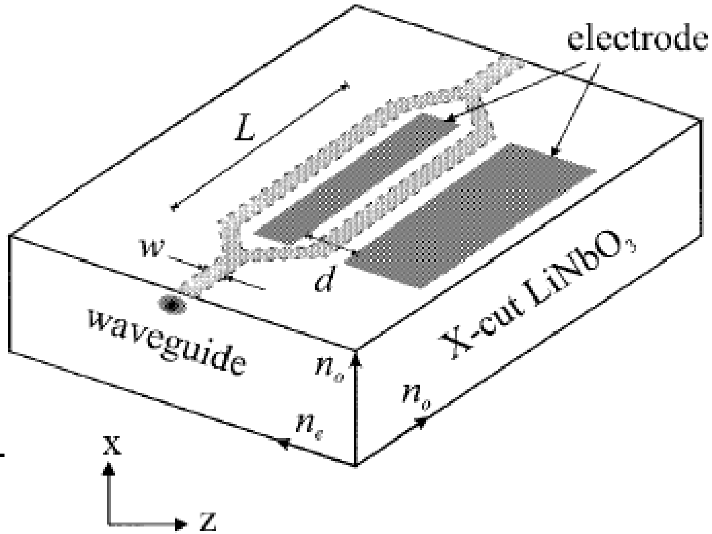


Fig. 4. Ridge height versus PE time for ridge waveguides in z-cut $LiNbO_3$. The proton exchange is done in pyrophosphoric acid at 240 and 260 °C.

X-cut $LiNbO_3$

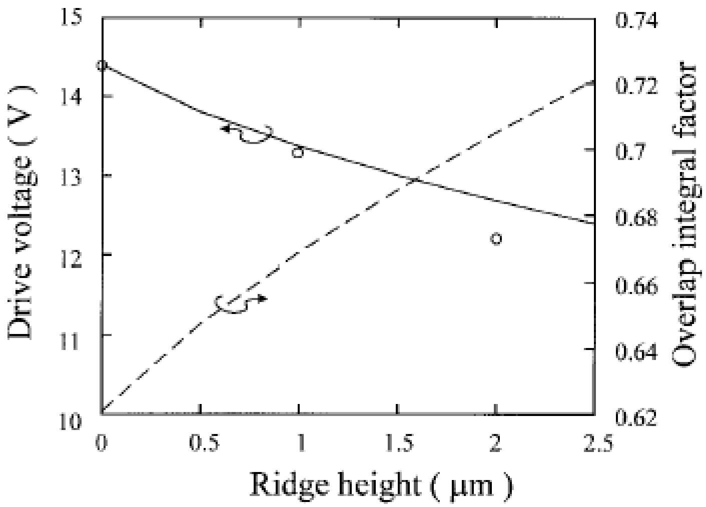
Same process steps as Z-Cut
Method 2



1. Tantalum mask evaporation 1000-Å x 6 μm– electron-gun evaporator / standard lift-off
2. Immersion in benzoic acid - 200º C for 1-6 hr
3. Nickel Deposition of 300-Å x 4 μm – electron-gun evaporator / standard lift-off
4. Nickel Diffusion - 800º C for 1 hr
5. Aluminum film electrodes – evaporation / etching

Experimental Results [3]

Ridge structure can lower the drive voltage



Theoretical Drive Voltage

$$V_\pi = \frac{\lambda d}{n^3 r_{33} L \Gamma}$$

Overlap Integral Factor

$$\Gamma = \frac{d}{V} \frac{\int\int E_{op}^2(x,z) E_{el}(x,z)\, dx\, dz}{\int\int E_{op}^2(x,z)\, dx\, dz}$$

Y-cut $LiNbO_3$

Immediate fabrication issue:

Y-plane is not an easy glide plane!

This means: Due to large stresses incurred from the PE process, we have formation of cracks in the x-direction.

EXTENSIVE SURFACE DAMAGE!!

Y-cut $LiNbO_3$

- Two proposed methods [2]:
  - Titanium Indiffusion Proton Exchange
  - Buffered proton exchange melt technique

Titanium Indiffusion Proton Exchange

- Ti causes negative strain – counteracts positive strain induced by PE process
- Ni also causes negative strain but at a lower temperature

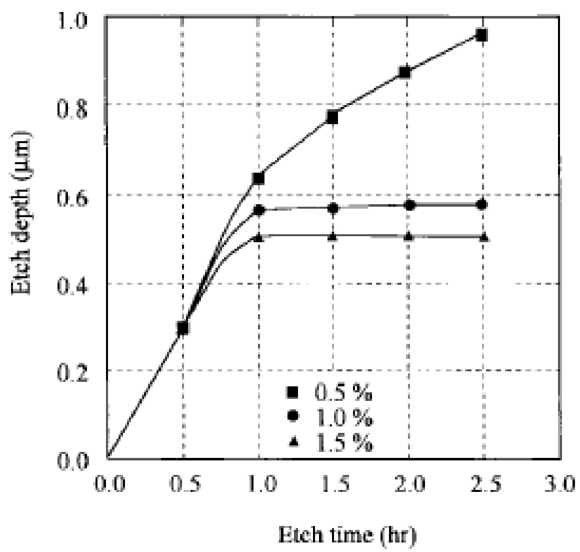
Buffered PE melt technique

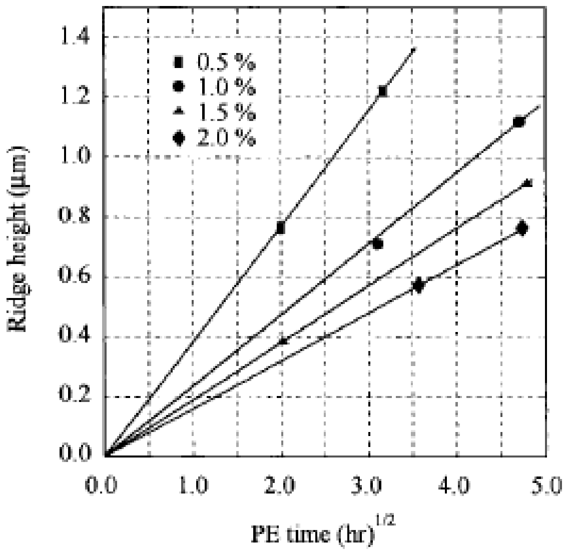
Key : Reduce H^+-ion concentration during PE

Result : Less strain

How? Dilute benzoic acid (C_6H_5COOH) with lithium benzoate (C_6H_5COOLi)

$$R = \frac{\text{moles of } C_6H_5COOLi}{(\text{moles of } C_6H_5COOLi) + (\text{moles of } C_6H_5COOH)} \times 100\%.$$





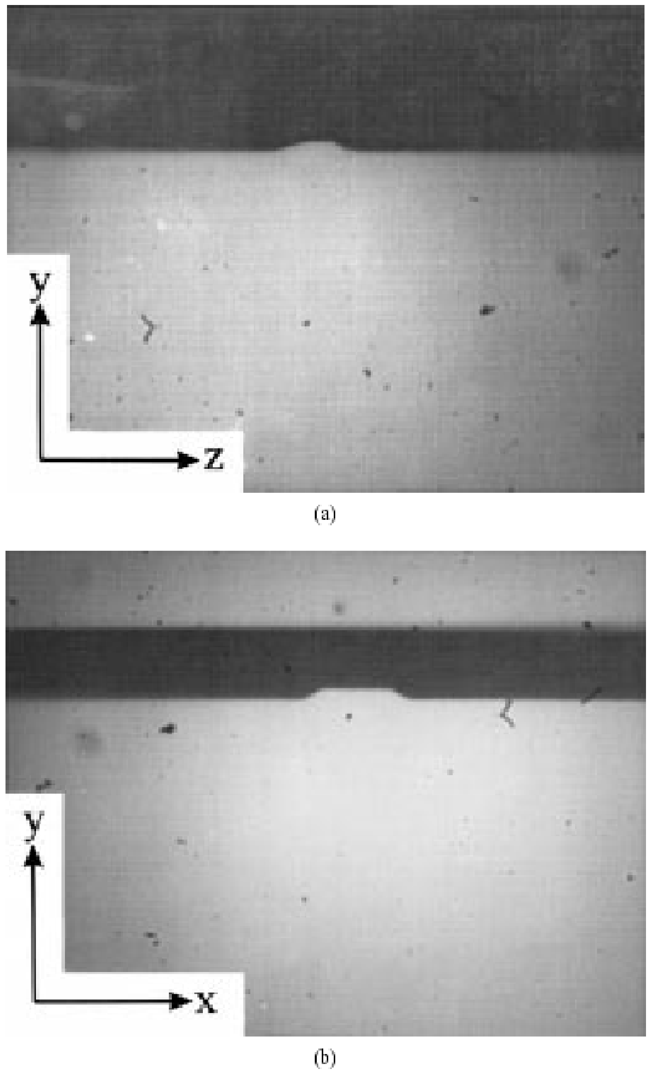


Fig. 15. Wet-etched y-cut ridge waveguides: (a) cross section on the y-z plane and (b) cross section on the x-y plane.

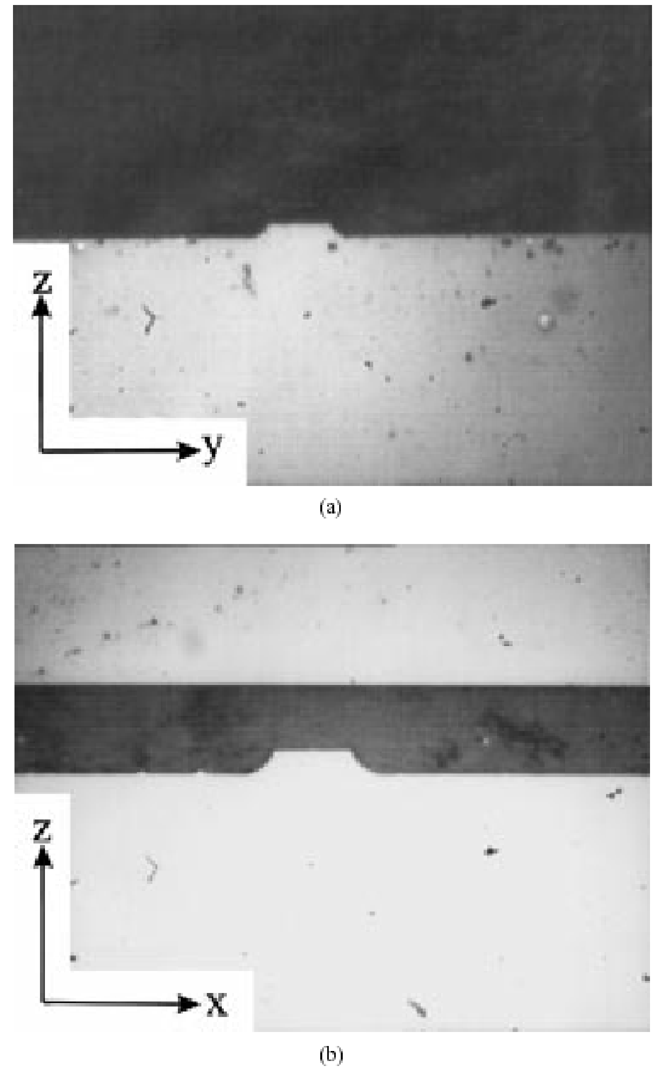


Fig. 16. Wet-etched z-cut ridge waveguides: (a) cross section on the y-z plane and (b) cross section on the x-z plane.

Conclusion

External Modulators have zero-chirp parameters

Ridged structures lead to lower drive voltages

Lithium Niobate is versatile substrate for optical waveguides – can be cut in three different orientations

Codeon Corporation

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Mach 10
External Optical Modulator

General	
Material	Ti:LiNbO$_3$
Package	Hermetic
Connectors	
RF	K
Bias	SMA or DC Pins
Fibers	
Input	PM Panda
Output	SMF-28 or PM Panda
Absolute Maximum Ratings	
Optical Input Power	50 mW
Operating Temp.	0 to 70 °C
Storage Temp.	-40 to +85 °C
RF Input Power	+27dBm

Key Features

- Low Drive Voltage
- Long-Term Bias Stability
- Hermetic packaging
- Zero Chirp
- C&L Band Operation

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References

- [1] Rajiv Ramaswami and Kumar N. Sivarajan, *Optical Networks: A Practical Perspective*, 2 ed., San Diego: Academic Press, 2002.
- [2] Rei-Shin Cheng, Tzyy-Jiann Wang, and Way-Seen Wang, “Wet-Etched Ridge Waveguides in Y-Cut Lithium Niobate,” *Journal of Lightwave Technology,* vol. 15, no. 10, pp. 1880-1887, 1997.
- [3] Shih-Jung Chang, Ching-Long Tsai, Yih-Bin Lin, Ju-Feng Liu, and Way-Seen Wang, “Improved Electrooptic Modulator with Ridge Structure in X-Cut $LiNbO_3$,”Journal of Lightwave Technology, vol. 17, no. 5, pp. 843-847, 1999.
- [4] Fredrik Laurell, Jonas Webjörn, Gunnar Arvidsson, and Johan Holmberg, “Wet Etching of Proton-exchanged Lithium Niobate – A Novel Processing Technique,” *Journal of Lightwave Technology*, vol. 10, no. 11, pp. 1606-1609, 1992.