Titanium-Indiffused $LiNbO_3$ Waveguide Fabry-Perot Modulator

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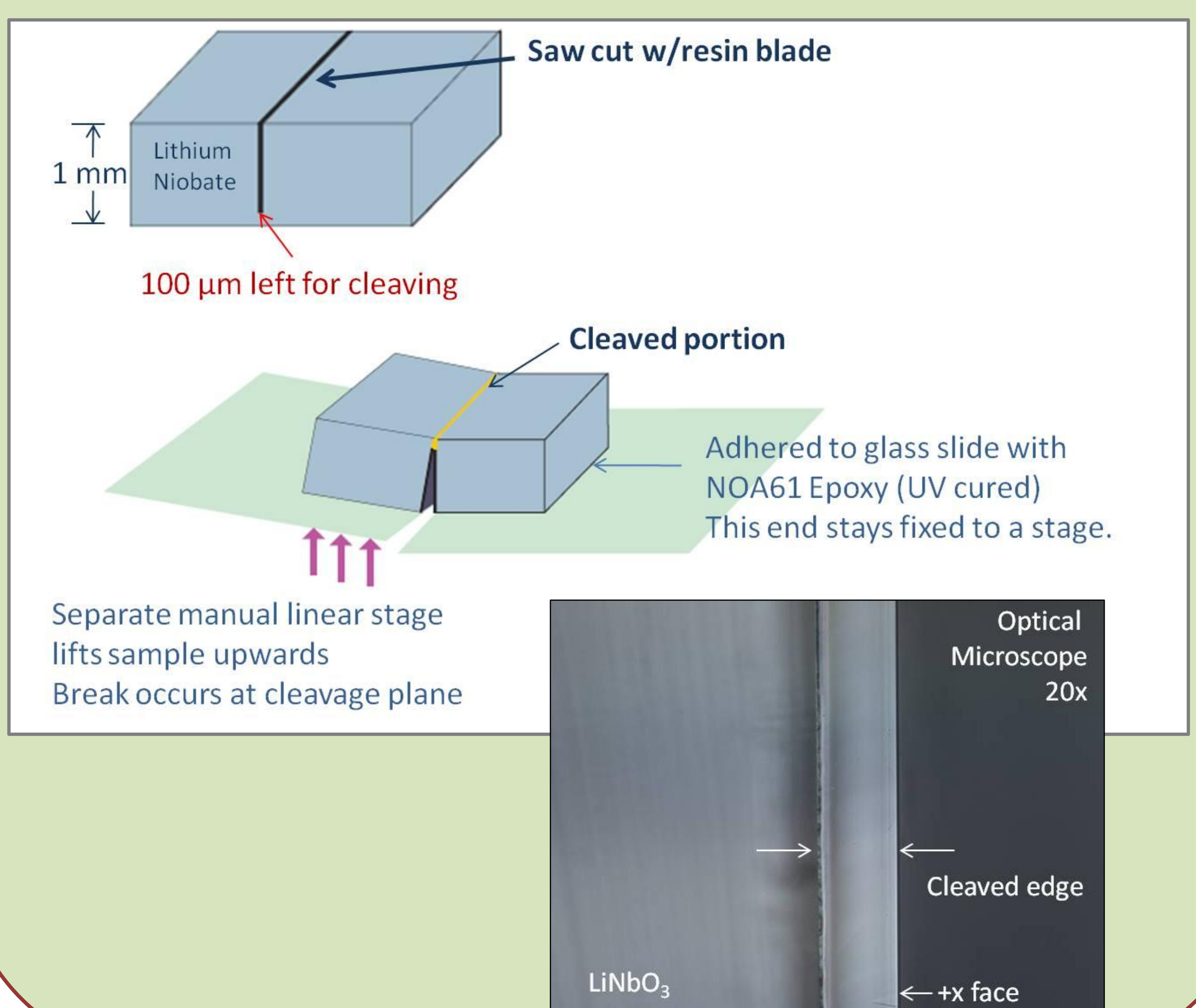
Motivation

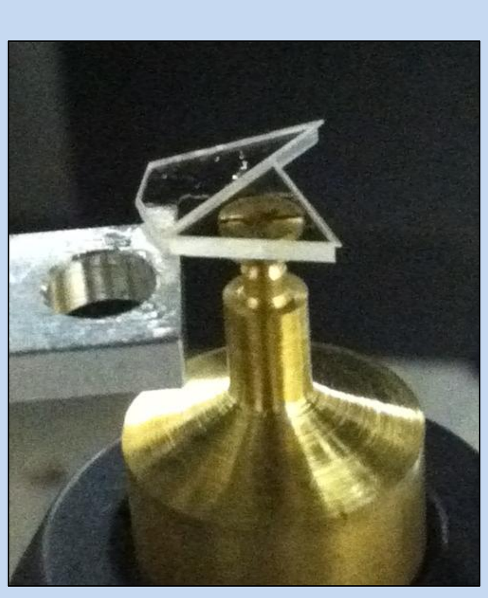
Lithium Niobate ($LiNbO_3$) is one of the most common electro-optic materials used as modulators for optical communication. A resonant waveguide can be formed by indiffusion of titanium in $LiNbO_3$, along with mirror facets. With the use of electrodes, the optically resonant structure can be modulated with an RF signal. Mirror facets require highly polished edges. Utilizing the cleaved planes of $LiNbO_3$ can eliminate the need for polishing. The cleaved plane of x-cut $LiNbO_3$ require two different waveguide orientations for the ordinary and the extraordinary mode, to obtain proper power confinement as a resonator.

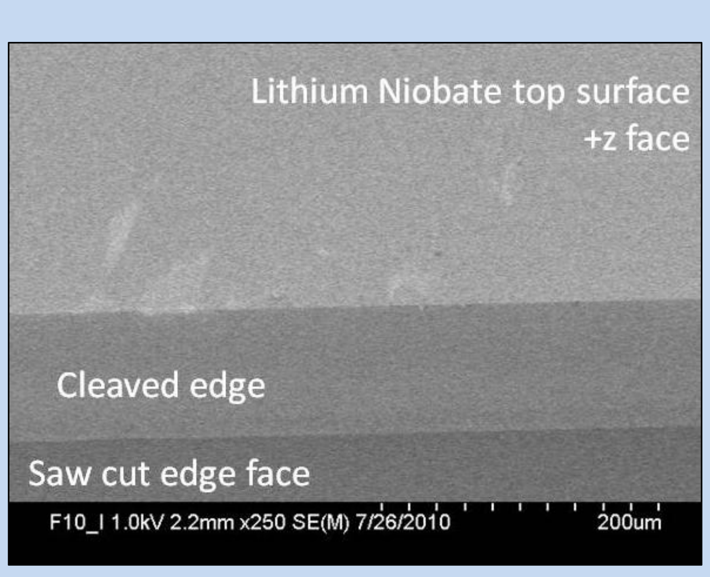
Cleaving $LiNbO_3$



Equilateral Triangle Resonator

Utilizing the cleaved planes of LiNbO3, an equilateral triangle resonator can be fabricated. A coupler is used to excite the mode within the resonator.

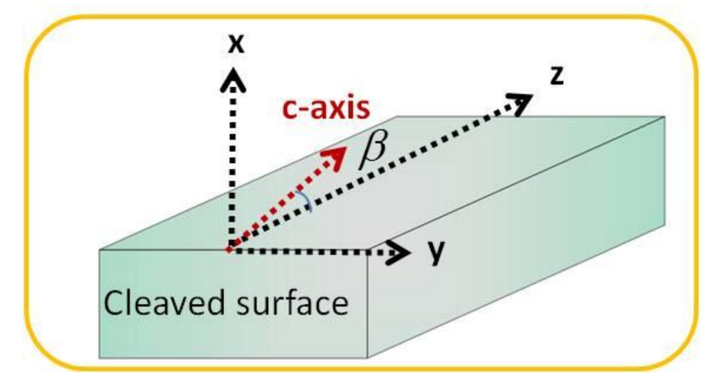




Theory

x-cut $LiNbO_3$ with cleaved edge
Off-axis dielectric tensor terms

$$\bar{\bar{\varepsilon}} = \begin{bmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & (\varepsilon_{33}-\varepsilon_{11})\sin^2\beta+\varepsilon_{11} & (\varepsilon_{11}-\varepsilon_{33})\frac{\sin 2\beta}{2} \\ 0 & (\varepsilon_{11}-\varepsilon_{33})\frac{\sin 2\beta}{2} & (\varepsilon_{33}-\varepsilon_{11})\cos^2\beta+\varepsilon_{11} \end{bmatrix}$$



Case 1: Ordinary wave only $E_x \neq 0$

$$\hat{\gamma}^o = \hat{z}\, j\omega\sqrt{\mu\varepsilon_{11}}$$ Propagation vector

$$\bar{S}^o = \hat{z}\left(E_x^o\right)^2 \frac{\beta_z^o}{\omega\mu}$$ Poynting vector

Case 2: Extraordinary wave E_y and $E_z \neq 0$

$$\hat{\gamma}^e = \hat{z}\, j\omega\sqrt{\frac{\mu\varepsilon_{11}\varepsilon_{33}}{\varepsilon_{33}\cos^2\beta+\varepsilon_{11}\sin^2\beta}}$$ Propagation vector

$$\bar{S}^e = \left[\sqrt{1+\left(\frac{E_z^e}{E_y^e}\right)^2}\right]^{-1}\left[\hat{z}-\hat{y}\left(\frac{E_z^e}{E_y^e}\right)\right]$$ Poynting vector

where $$\frac{E_z^e}{E_y^e} = \frac{(\varepsilon_{33}-\varepsilon_{11})\sin\beta\cos\beta}{\varepsilon_{33}\cos^2\beta+\varepsilon_{11}\sin^2\beta}$$

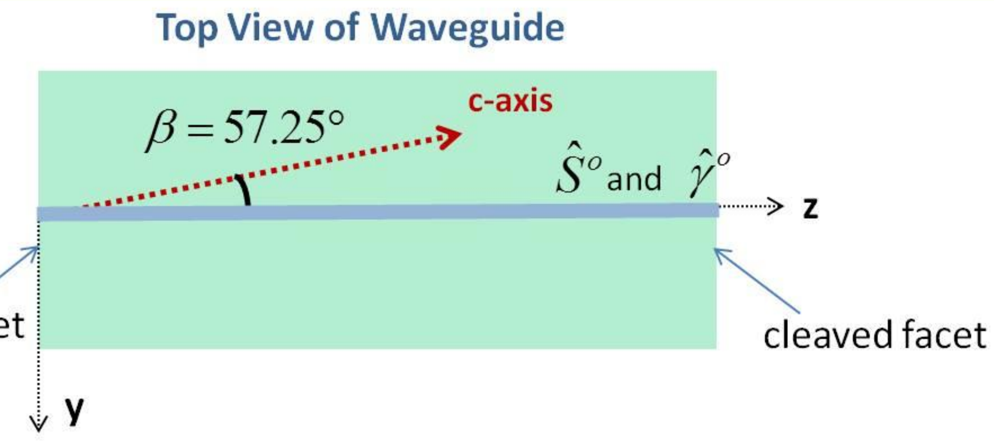
Angle between Propagation Vector and Poynting Vector

$$\Omega^e = \arccos\frac{1}{\sqrt{1+\left(E_z^e/E_y^e\right)^2}}$$

$\hat{\gamma}_z^{e,o}$ **must be perpendicular to the cleaved facet** to provide a standing wave for the Fabry-Perot

Top View of Waveguide

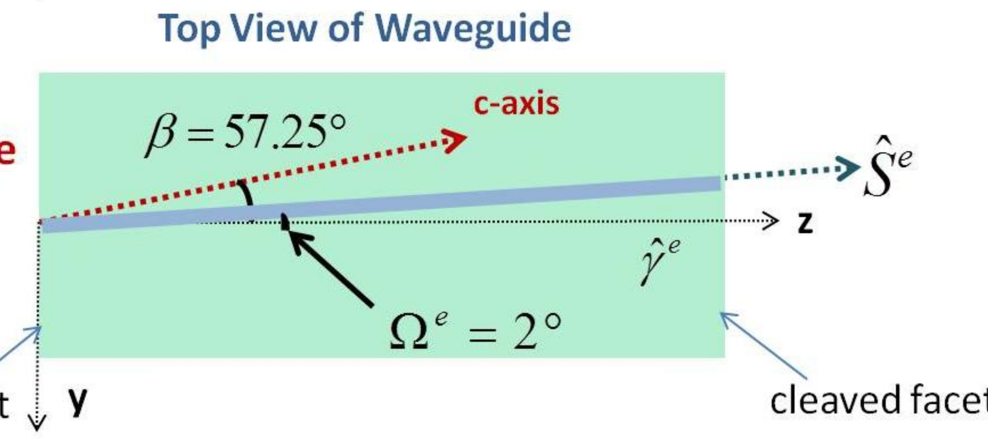
Case 1: Ordinary wave

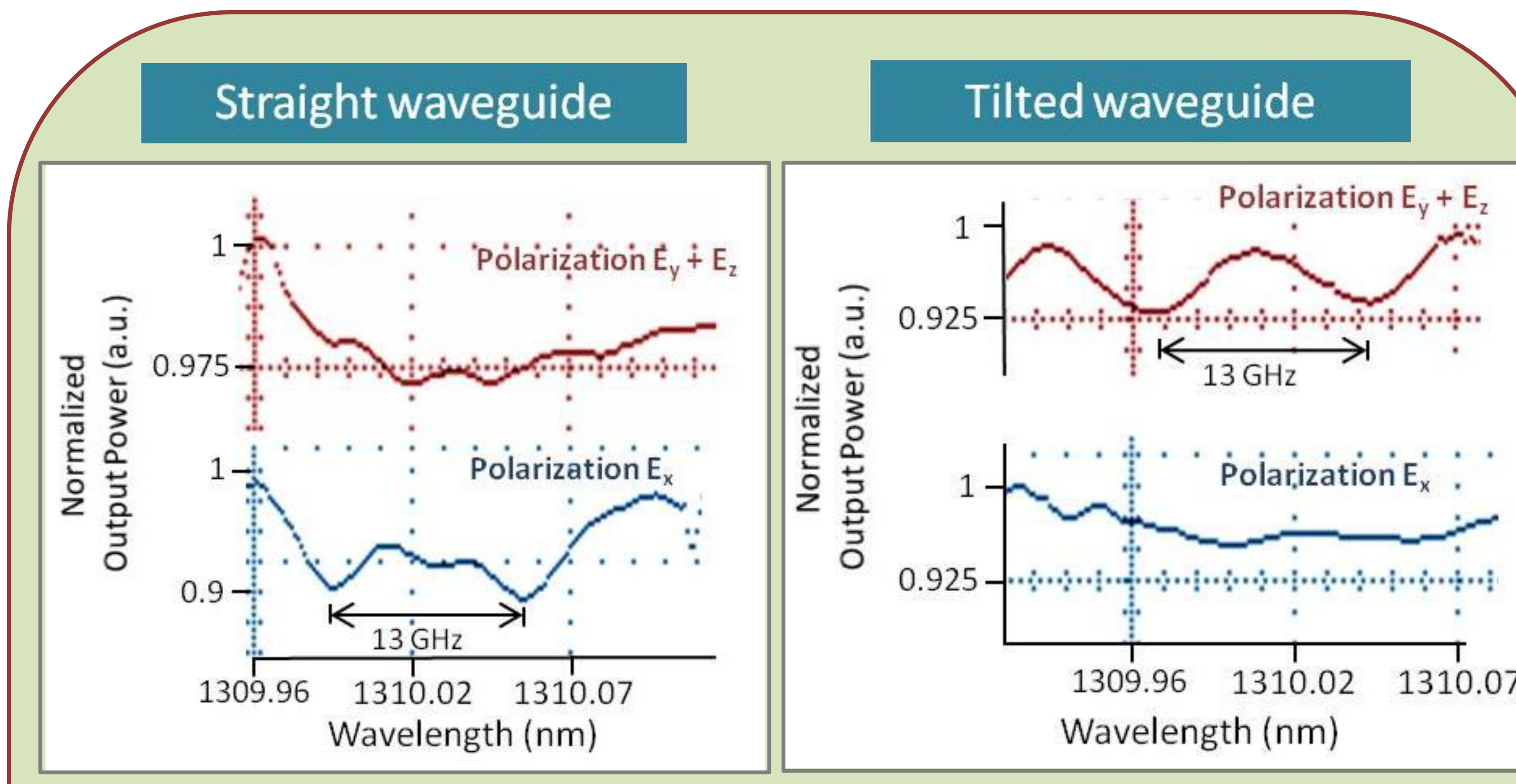


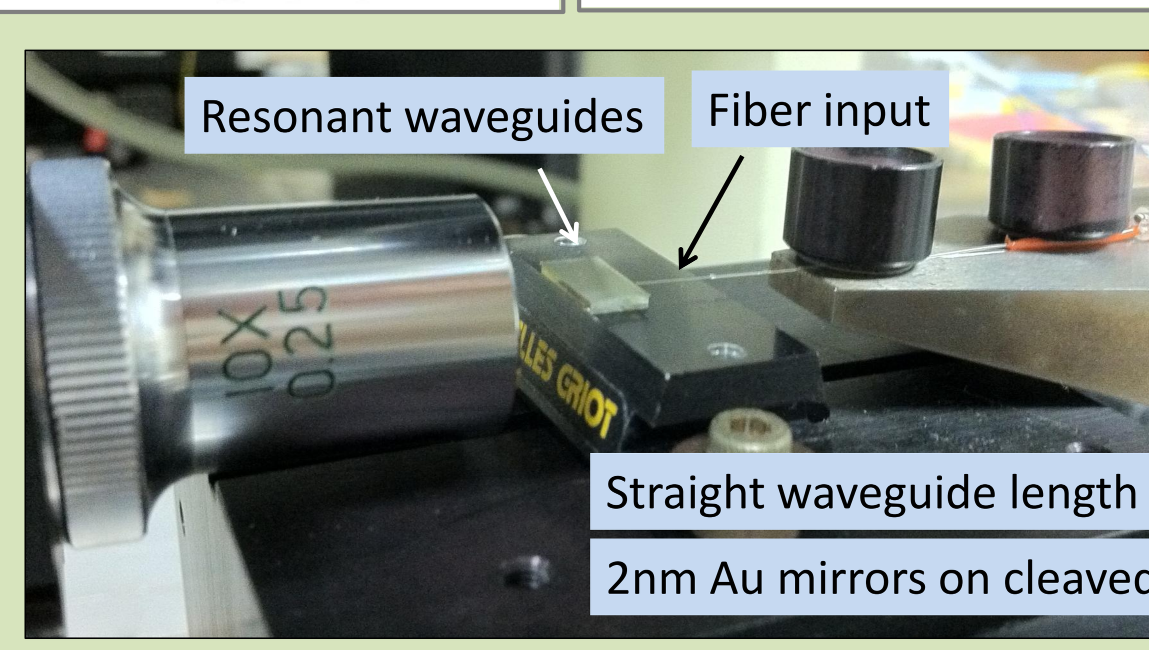
Top View of Waveguide

Case 2: Extraordinary wave

Tilted waveguide







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