Lithium Niobate Modulator

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Modulator

- There are two commonly used types of optical modulators in fiber optic communication systems: the electro-absorption modulator (EAM) and the Mach-Zehnder modulator.

- Advantages of LiNbO₃ modulator:
  - Enough bandwidth
  - Minimized effects of dispersion
  - Stable operation over temperature,
  - Very low bias-voltage drift rates, and bias-free devices.
LiNbO3 Wafer

- LiNbO3 has been the material of choice for the fabrication of electrooptic modulators
  - high electrooptic coefficients
  - high optical transparency for wavelengths used for telecom.
  - high Curie temperature (1100 C–1180 C) makes it practical for fabrication of low-loss optical waveguides through indiffusion of metals.
  - thermally, chemically, and mechanically stable
  - compatible with conventional integrated-circuit processing technology
  - May susceptible to optical damage if Fe ion contaminated during crystal growth
  - Z-cut wafer need special care and packaging consideration to avoid bias drift caused by charge migration and buildup pyroelectric charge.
Waveguide Fabrication

- **Ti Infusion near 1000°C**
  - Presence of Ti in LiNbO3 crystal increase both ordinary and extraordinary indexes of refraction. With proper concentration, TE and TM can propagate in the waveguide.

- **Annealed proton exchange**
  - 120-250°C, Li exchange with ions from acid bath
  - Exchange layer exhibit high refractive index for extraordinary light only
  - APE waveguide is polarizing one
Electrode Fabrication

- RF electrodes are fabricated
  - on the surface of the LiNbO3 wafer or
  - on an optically transparent buffer layer to reduce optical loss due to metal loading and provide a means for optical/RF velocity matching.

- Process:
  - an adhesion layer, such as Ti, is first vacuum deposited on the wafer,
  - deposition of a base layer of the metal in which the electrodes are to be made.
  - The electrode pattern is then photolithographically defined.
  - Gold is generally used as the electrode metal.
  - Plating processes
  - After plating, the mask is removed and the metal in the gaps is etched away.
Substrates containing an array of finished modulators are cut from the LiNbO3 wafer using conventional water-cooled diamond saws.
End faces are cut at an angle to the waveguides to eliminate reflections and are then polished to an optical finish.
The modulators on a substrate are individually tested before the substrate is diced into individual components.
Requirements:
- Cleanliness must be maintained throughout the modulator fabrication process. Debris from dicing and particulates from polishing compounds are contaminants that can negatively impact the performance and long-term reliability of the modulators, and must therefore be removed during chip cleaning operations.
Chip Fabrication Summary

- Coating
- Photolithography
- Ti Evaporation
- Lift-off
- Diffusion
- SiO2 evaporation
- Cr-Au Electrodes
- Thick Photoresist
- Electroplating
- Dicing and polishing
Packaging

- Integrated-optic chip (previous slides)
- Optical-fiber assemblies
  - Polarization maintaining fiber as input
  - Normal SMF as output
  - Angled glass tube attached to fibers to avoid back-reflection
- Electrical or RF interconnects and housing.
  - Electrical interconnects soldered to the modulator housing
  - The pigtailed LiNbO3 chip is attached to the package
  - electrical interconnection between the package and the LiNbO3 chip is accomplished using either wire or ribbon bonds.
  - Hermetically sealed package
Design Consideration

- Design parameters
  - Insertion Loss
  - Driving Voltage
  - Microwave Loss
  - Microwave Index
  - Chirp
Design Consideration

- **Insertion Loss**: Match of waveguide and fiber mode

- **Driving Voltage**
  - $\Delta \Phi = \pi$ strongest modulation
  - $\Delta \Phi \sim \frac{V_{in}}{V_\pi}$, where $V_\pi$ half wave voltage that makes $\Delta \Phi = \pi$ at 0 frequency
  - Half wave voltage
  - For the same $V_{in}$, $\Delta \Phi$ decreases as increase of frequency
    - Electrode resistance
    - Absorption of WG dielectric
    - Velocity of mismatch between signal and carrier wave

\[ V_\pi = \frac{\lambda_0 d}{2n_{opt} r TL} \]
Microwave Loss

- Microwave loss

\[ \alpha = \alpha_c \sqrt{f} \]

Where \( \alpha_c \) is the conductive loss normalized to 1GHz.
Microwave Index

- Optical Response

\[
m(f) = \left[ \frac{1 - 2e^{-\alpha L} \cos 2u + e^{-2\alpha L}}{(\alpha L)^2 + (2u)^2} \right]^{1/2}
\]

where \( u = \frac{\pi f L (N_m - N_0)}{c} \) and \( \alpha = \alpha_c \sqrt{f} \)

- Frequency dependent Driving Voltage

\[
V_\pi(f) = V_\pi(dc) 10^{-m(f)/10}
\]

\( L \) is the length of the electrodes
\( N_m \) and \( N_0 \) are the effective indices of the microwave and the optical wave.
Chirp

- Chirp is an unwanted phase shift caused by light pulse broadening and thus limits the maximum frequency response of an optical link.
- X-cut LiNbO3 modulator are chirp free due to the push-pull symmetry of applied field in the electrode gap.