Chirp behavior of uncooled EMLs

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Review of EA modulator physics

- The temperature dependence of InP materials causes the absorption edge of the EAM to shift relative to the DFB wavelength at rate of ~ 4nm/°C.
- As the absorption edge shifts away from the DFB wavelength, it takes additional reverse bias voltage to shift it back to achieve the same absorption. Due to lower electron confinement at high applied field, there is a tendency for the absorption to be reduced at lower temperatures.
- The chirp and absorption curves are linked by the Kramers-Kronig relation and shift together over temperature.
- To first order, the inflection voltage of the extinction curve (Vea at max dP/dV) is close to the zero-chirp voltage, so Vinfl can be used as an approximate stand-in for the zero-chirp voltage. The chirp is then roughly proportional to the relative bias voltage, Vea – Vinfl.

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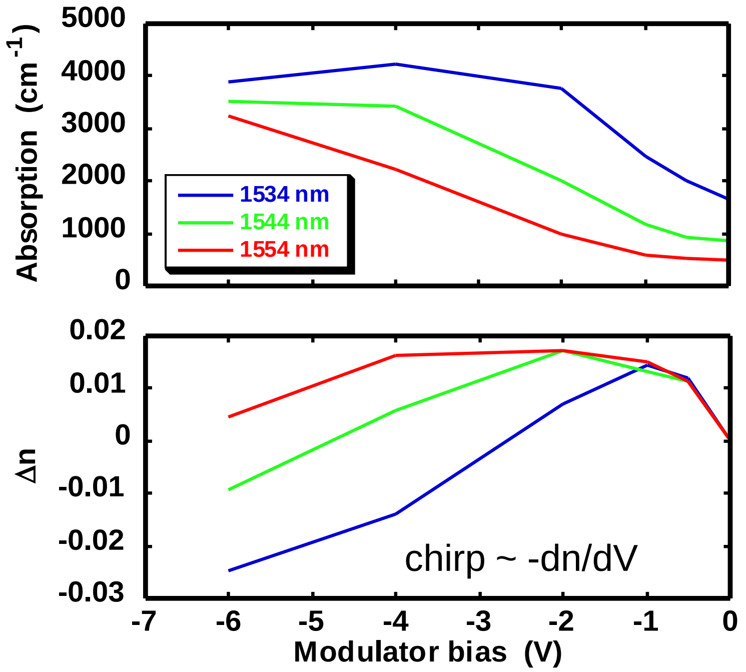
Chirp behavior of EA modulators

- The absorption and chirp of an EA modulator are linked mathematically by the Kramers-Kronig Relation.
- Chirp is always positive at low absorption, passes through zero and becomes negative at higher absorption.
- The EA bias voltage must be selected to simultaneously achieve OMA, ER, SECQ and CD penalty objectives.
  - It's well known from industry experience that EMLs must be optimized to have good performance in high-dispersion long-reach applications (e.g., 400GBASE-LR4).
  - EMLs designed for short-reach applications may not have sufficient ER or power at the bias required for low CD penalty in long-reach applications.

$$\Delta n = \frac{\pi}{c} PV \int_0^\infty \frac{\alpha(\omega')}{\omega'^2 - \omega^2} d\omega'$$

$$\Delta\omega = -\frac{d\phi(t)}{dt} = -\frac{\omega_o}{c}\frac{dn}{dV}\frac{dV(t)}{dt}$$



Tuning an uncooled EML TX over temperature

- The EML DFB bias current and EAM bias voltage must be tuned to simultaneously meet OMA, ER, SECQ and TDECQ (CD penalty) at each temperature.
  - OMA: At high temperature, DFB bias must be increased to compensate for lower slope efficiency and higher EAM insertion loss, so more positive Vea may be needed to meet the minimum OMA target.
  - ER: At low temperature, more negative Vea may be needed in order to meet the minimum ER target.
  - SECQ: The best linearity and lowest SECQ is generally (but not always) obtained close to Vinfl.
  - TDECQ: CD penalty has little dependence on chirp for DR/FR reaches but is very important for LR reach.
- An EML that works well for 400GBASE-FR4 may have a high 10km CD penalty if the EAM bias relative to the inflection point can't be kept reasonably constant over temperature.

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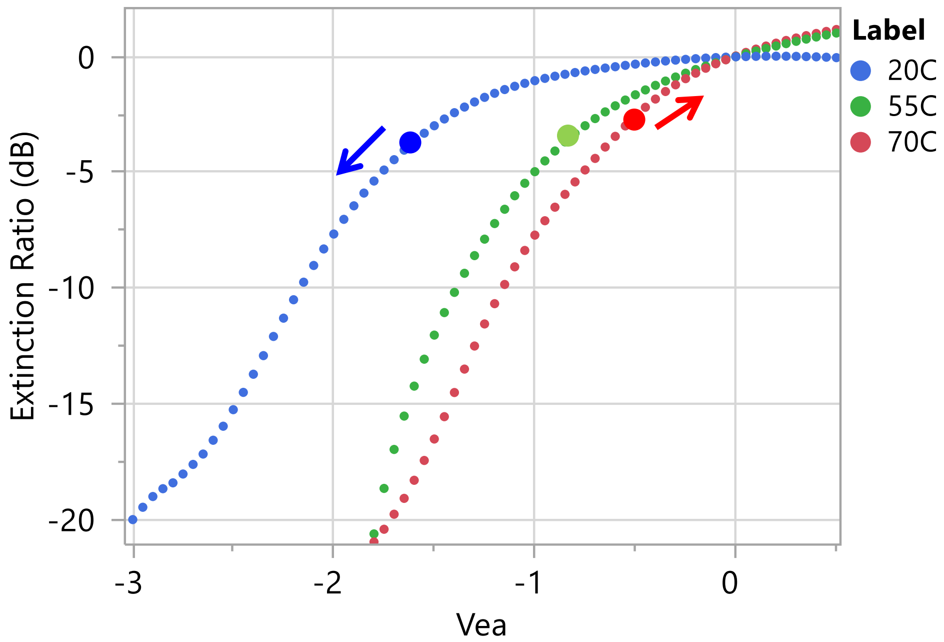
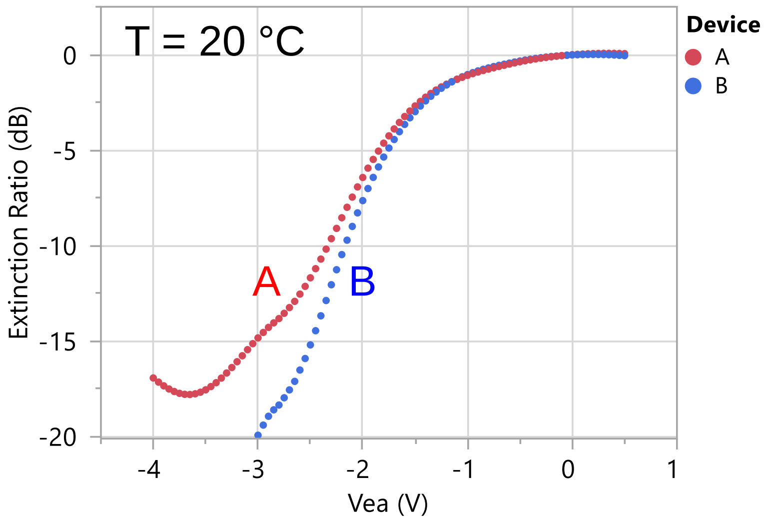
Uncooled EAM extinction curves



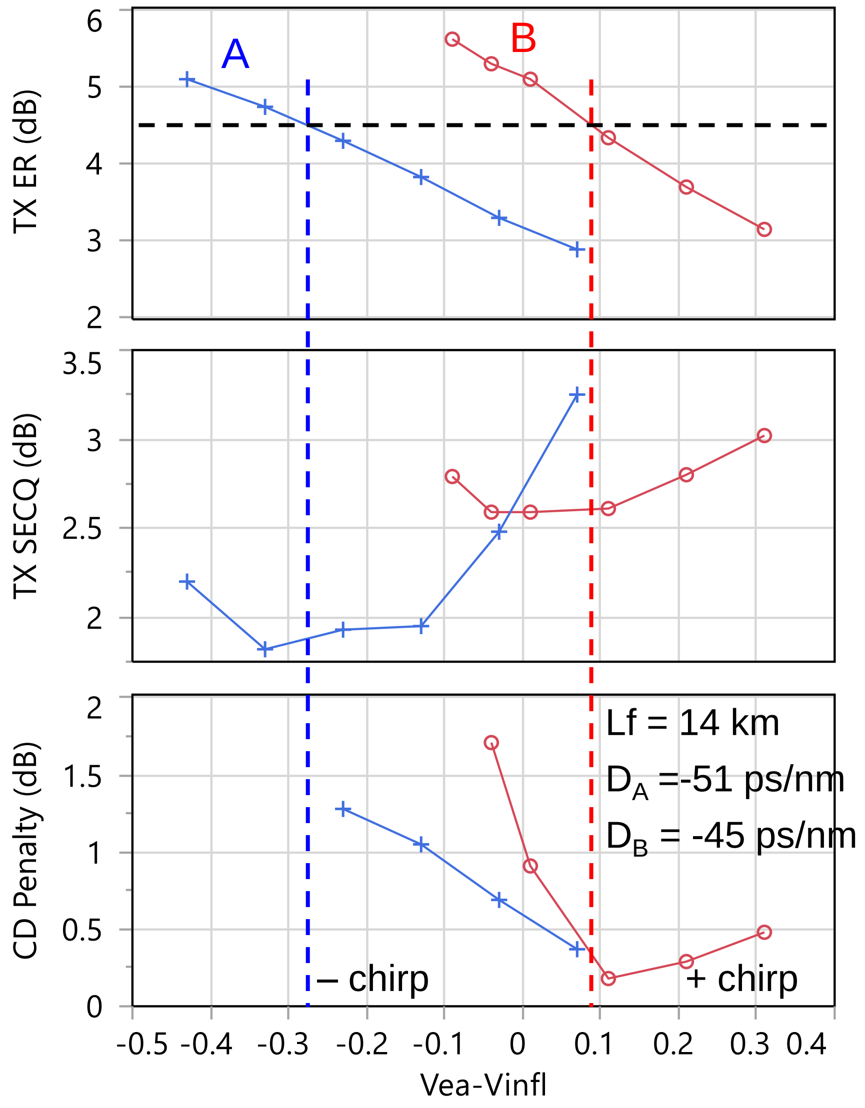
- For consistent chirp behavior, the bias voltage should track Vinfl over temperature.
- Insufficient optical power or ER in short-reach designs can force the bias to deviate at high and low temperatures.

- As temperature decreases, the extinction curves shift to more negative bias, and chirp follows per the K-K relation.
- The dots show the locations of the (linear) inflection voltages for a DR/FR EML.
- At lower temperature (20 °C),
  - The extinction slope at Vinfl is lower
  - The ER for a fixed voltage swing centered at Vinfl is lower
  - As a result, more negative bias may be required to achieve target ER, resulting in more negative chirp.
- At higher temperature (70 °C),
  - DFB laser output power may be limited
  - EAM insertion loss is higher
  - As a result, more positive bias may be required to achieve target OMA, resulting in more positive chirp.

Example: Two 1270nm EMLs over 14 km fiber



- Vinfl ~ -1.6V for both, but Device B has higher ER than Device A.
- **Device A** must be biased more negative relative to Vinfl in order to meet a 4.5 dB target ER, resulting in **negative chirp** and large CD penalty with -51 ps/nm dispersion.
- **Device B** can be biased positive relative to Vinfl, resulting in zero to slightly **positive chirp** and low CD penalty.
- At Vea – Vinfl > 0V, **both** devices have low CD penalties.
- **Uncooled 1270nm EMLs must be designed to have adequate ER for LR applications or CD penalty can be large.**



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Summary

- The behavior of uncooled CWDM EML chirp over temperature can be adequately explained in terms of the EA bias needed to meet OMA and ER targets.
  - CWDM EMLs in short-reach 400GBASE-FR4 applications can be biased above or below the inflection voltage as needed without incurring significant CD penalty.
  - Using 400GBASE-FR4 EMLs for 400GBASE-LR4 may lead to excessive CD penalties at 1270nm at cold temperature and 1330nm at hot temperature as the bias is pushed away from the inflection point.
- CWDM EMLs for uncooled 400GBASE-LR4 should be optimized to provide additional OMA and ER in order to limit the spread of chirp over temperature.
  - This is not an unprecedented transition in the industry. The same kind of device optimization occurred with 10Gb/s EMLs to push transmission distance from 40km to 80km.
- The CWDM grid is the best choice for the industry for 400GBASE-LR4
  - Cooling provides a path to use existing short-reach CWDM EMLs in 400GBASE-LR4 modules by limiting the ranges of **both** the wavelength (fiber dispersion) and EAM chirp.
  - With EMLs optimized for additional OMA and ER margin, 400GBASE-LR4 modules can operate uncooled and will interop with the CWDM receivers in cooled and uncooled modules.
  - Using a LAN-WDM grid is an economic dead-end with few options for future cost reduction.

Thank you!