Modal leakage in interband cascade lasers diagnosed using far-field optical profilometry

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Interband cascade lasers (ICLs) have demonstrated the ability to emit a pattern of sharp equidistant lines with fixed phase relationship referred to as an optical frequency comb (OFC). Such sources covering the spectroscopically-important 3–5 μm mid-infrared wavelength region are highly suitable for dual-comb spectroscopy, where two OFCs are optically heterodyned to resolve individual comb lines without any moving parts. Given the interband cascade structure's ability to either emit or detect light, one can envision fully-integrated comb sources and detectors defined photolithographically on the same chip for broadband on-chip spectroscopy. However, the high refractive index of the GaSb substrate poses a significant challenge for waveguiding. Because the ICL's modal index is lower than that of GaSb, the lasing mode can leak through an insufficiently-thick clad layer and reflect from the metallic bottom contact. This effectively forms a vertical, low-finesse Fabry-Pérot resonator, which induces quasi-periodic interferometric modulation of the gain and group velocity dispersion (GVD) that severely limits the spectral coverage and stability of an ICL comb.

Another effect related to modal leakage is distortion of the far-field (FF) profile in the vertical (growth) direction. We found that FF profilometry of ICLs provides a wealth of information for modal leakage diagnostics. Unintended light emission from the large-aperture GaSb substrate produces sharp, narrow peaks (sidelobes) in the FF profile at angles governed by the index ratio of the mode to the substrate, which in the case of GaSb ICLs can reach almost 90º. Although total internal reflection inside the device makes the sidelobes disappear at certain ratios, the oscillations persist for leaky-mode devices. The opposite is also true: devices with smooth, non-modulated FF profiles generally exhibit single-lobed optical spectra with only minor gain and GVD oscillatory features, signifying non-corrupted waveguiding. The talk will compare the results of FF profilometry for ICL devices with different ridge widths and operating at different wavelengths to conventional amplified spontaneous emission (ASE) spectroscopy. We will discuss the implications of modal leakage for ICL comb performance, and highlight how it can be leveraged to tailor the spectral properties.

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