Quantum Confined Stark Effect Absorption in an Edge-Emitting Light-Emitting Diode

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EELED, LED, quantum well, reflectometry

The quantum-confined Stark effect is employed to form an integral reverse-biased absorber in a GaInAsP edge-emitting light-emitting diode. Optical low-coherence reflectometry is used to measure the magnitude of reflections through this absorber. Front facet-back facet round trip reflection magnitudes are below -110 dB in devices having an antireflection coating on the front facet only. All other round trip reflections are below -80 dB. This device provides a wide usable dynamic range in optical low coherence reflectometry measurements.

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Quantum-confined Stark effect (QCSE) absorption[1,2] was employed to reduce the effective magnitude of the back facet reflection in an edge-emitting light-emitting diode (EELED). Reverse biasing quantum wells yields a large increase in absorption just below the zero-field bandgap energy, leading to a back facet return loss so low that it could not be measured accurately using the sensitive technique of optical low coherence reflectometry (OLCR).[3,4] This device provides a wide usable dynamic range in OLCR experiments. The design could be useful in other applications as well; since QCSE absorption is considerably stronger than loss mechanisms in most conventional EELEDs it should block lasing at low temperatures more effectively .

Our EELED, shown in Fig. 1, is a continuous waveguide device containing a 300 μm-long forward-biased gain contact and an 880 μm-long reverse-biased absorber contact separated by a 100 μm unbiased gap. An unbiased region, approximately 20 μm long, is present at the absorber end of the device, yielding a total device length of 1300 μm. Device fabrication begins with a full 1.3 μm-emitting quantum well separate confinement heterostructure (SCH) grown by metalorganic chemical vapor deposition (MOCVD). The epitaxial layers are a 1.5 μm-thick *n*-type InP lower cladding layer on an *n*-type substrate, a 2000 A SCH layer, four undoped quantum wells (L_z = 90 A) and three undoped barriers (L_b ~ 200 A), an undoped 2000 A SCH layer, a 2.3 μm-thick *p*-type InP upper cladding layer, and a 0.2 μm-thick *p*-type $Ga_{0.47}In_{0.53}As$ contact layer. The SCH and barrier layers are composed of $Ga_{1-x}In_xAs_{1-y}P_y$ with a bulk bandgap corresponding to an emission wavelength of 1.1 μm. The quantum well quaternary material's bulk bandgap corresponds to an emission wavelength of 1.4 μm. All layers are nominally lattice-matched to InP, so the structure contains no intentional strain. Processing is similar to that for a two-growth semi-insulating planar buried heterostructure laser.[5] Wet chemical etching defines a mesa down to the n-InP lower cladding layer. Semi-insulating InP:Fe is regrown around the mesa to confine current to the active region while providing optical confinement and good thermal conduction from the active region. Separate gain and absorber contacts are evaporated on the top of the wafer after SiO_2 removal. The wafer is thinned and a continuous contact is evaporated over the entire backside of the wafer. Both the front and back facets of the EELED are cleaved similarly to a laser. 300 μm-long single-contact lasers produced with this process have thresholds of 15 mA.

For testing, a current source drives the forward-biased (short) gain contact, while a negative voltage is applied to the (long) absorber contact. The EELED is coupled into a single mode fiber to serve as the source in the OLCR measurement. The light is split in a 3 dB fiber directional coupler and enters the two arms: a mirror on a translation stage terminates the reference arm, and a stationary mirror replaces the DUT in the other arm. Reflected signals are recombined in the coupler and travel to a detector. When the path lengths of both arms are equal the signals from the two arms add coherently and produce a strong interference signal at the detector. When the optical path length difference becomes larger than the coherence length of the source, the interference signal no longer exists. Ideally, no other interference signals should occur as translating the movable mirror increases the path length difference further, because the mirror serving as the DUT should have only one reflection. However, multiple round trip reflections inside the EELED source can cause interference sidelobes when the round trip path length difference matches the optical round trip distance of the internal reflections. In OLCR these undesirable source reflections appear as low level sidelobes placed symmetrically around major reflections from the device under test.

Using a single high reflector as the DUT with the EELED forward-biased at 75 mA DC and the absorber contact open, a reflectivity of -49 dB was measured for the back facet reflection signal. Applying a reverse bias to the back contact is expected to move the absorption edge of the absorber region to a longer wavelength, reducing the magnitude of the signal reflected from the back facet. This behavior is shown in Fig. 2. Applying a -4 V bias to the back contact reduces the back facet reflection signal by over 35 dB compared to the case when the back contact is left open, resulting in a sidelobe level of -85 dB. This reflectivity is far lower (by 20 to 45 dB) than back facet reflection signals we have measured on commercially available GaInAsP EELEDs. The measured power coupled from this device, which is *not* mounted on a heatsink, into a single mode fiber is 6 μW.

Because absorption in semiconductor quantum wells is stronger at shorter wavelengths than at longer wavelengths (aside from excitonic effects), light transmitted out the back facet of the device should peak at longer wavelengths than light emitted from the front gain contact. Back facet emission should move to progressively longer wavelengths as the magnitude of the reverse bias voltage is increased. This spectral behavior is illustrated in Fig. 3. Both the gain and the absorber contacts are forward biased for curves (a) through (d). The absorber is left open for curve (e) and biased from 0 (short circuit) to -3 V for curves (f) through (h). The peak wavelength increases over 100 nm through the full range of bias conditions. An abrupt loss of short wavelength emission is observed when the nominal absorber is no longer forward biased, from curves (d) to (e).

A multi-layer antireflection coating was deposited on the front facet of the EELED to further reduce reflection magnitudes by an additional 25 to 30 dB. Figure 4 shows the OLCR output of an EELED at 50 mA with the back contact open after the anti-reflection coating. No secondary reflections from any source are observed down to the noise floor, below -80 dB, which results from shot noise.[6] Sidelobes due to the back facet reflection are inferred to be -110 dB or lower for a -4 V reverse-biased absorber. Adding an antireflection coating to the back facet of the device could further reduce these sidelobes to less than -135 dB.

In summary a long, reverse-biased quantum Stark effect absorber has been used to attenuate front facet - back facet reflections within an EELED to below -80 dB. The addition of a multilayer antireflection coating on the front facet reduces the loss for this reflection signal to an inferred value of -110 dB, and reduces the loss for all internal reflections to a measured value better than -80 dB. This EELED design allows large dynamic range OLCR measurements without the symmetric sidelobes caused by internal source reflections.

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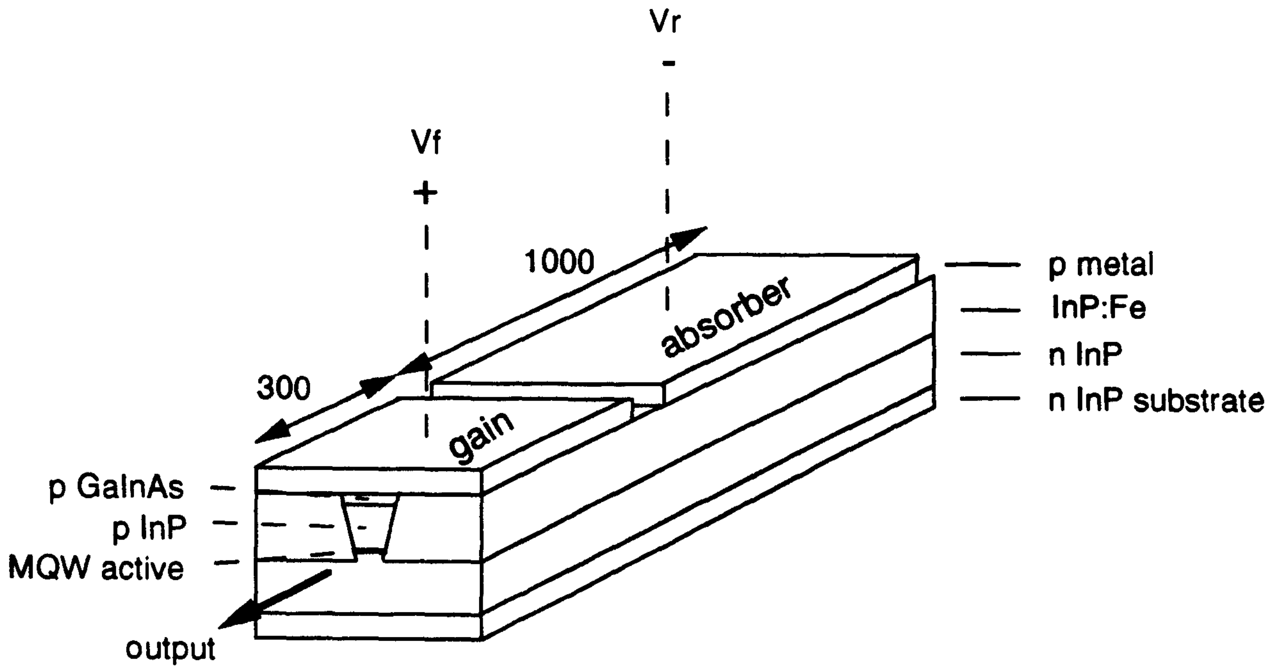

Figure 1: The EELED contains a continuous waveguide with a quantum well active region. The forward-biased gain region produces 1.3 μm emission while the absorber attenuates round trip reflections.

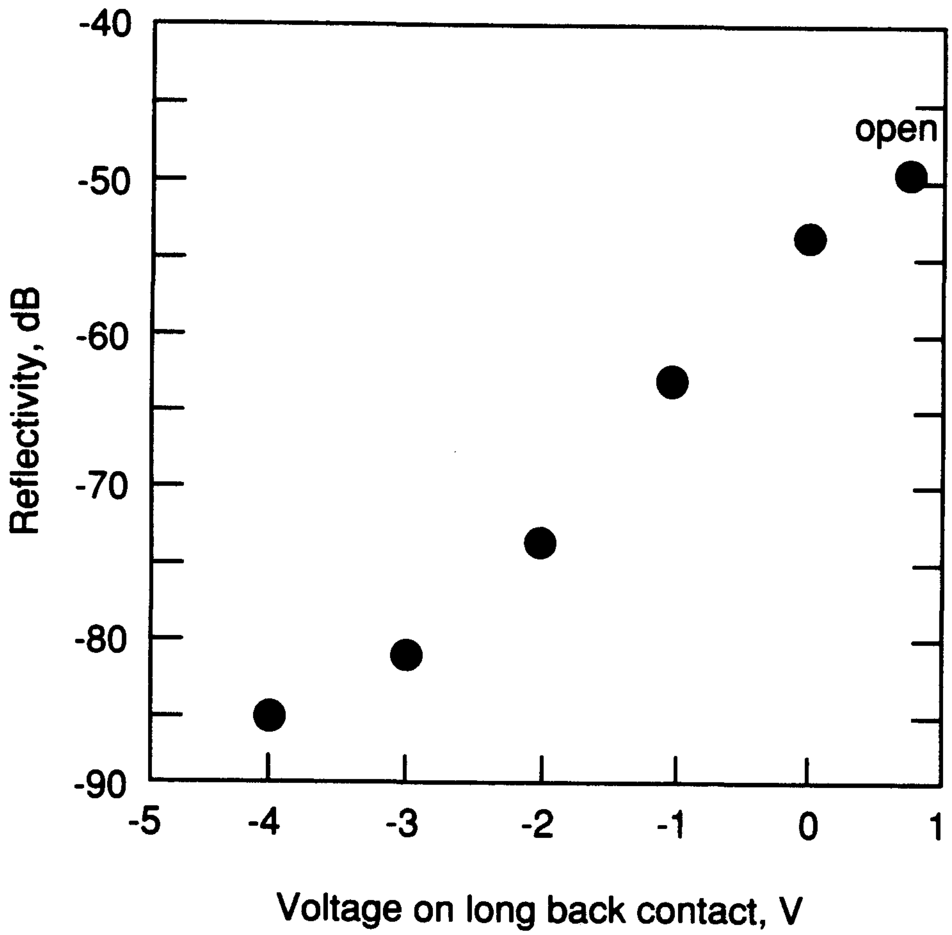

Figure 2: The magnitude of the back facet OLCR reflection signal decreases with increasing magnitude of the reverse bias voltage applied to the absorber as the quantum-confined Stark effect blocks longer wavelengths. The back facet reflection falls to -85 dB at a bias of -4 V.

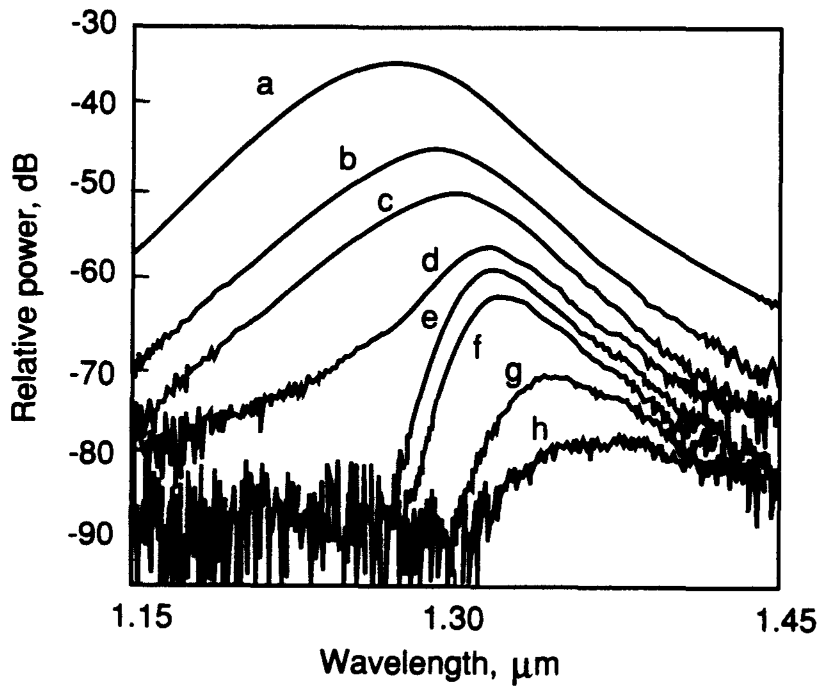

Figure 3: Emission spectra from the 50 mA forward-biased gain region through the absorber and out the back facet depend on the bias applied at the the back contact: forward biases of (a) 75, (b) 10, (c) 5, (d) 1 and (e) 0 mA; reverse biases of (f) 0, (g) 1.5 and (h) 3 V. Applying a reverse bias decreases transmission and shifts the transmission peak to longer wavelengths.

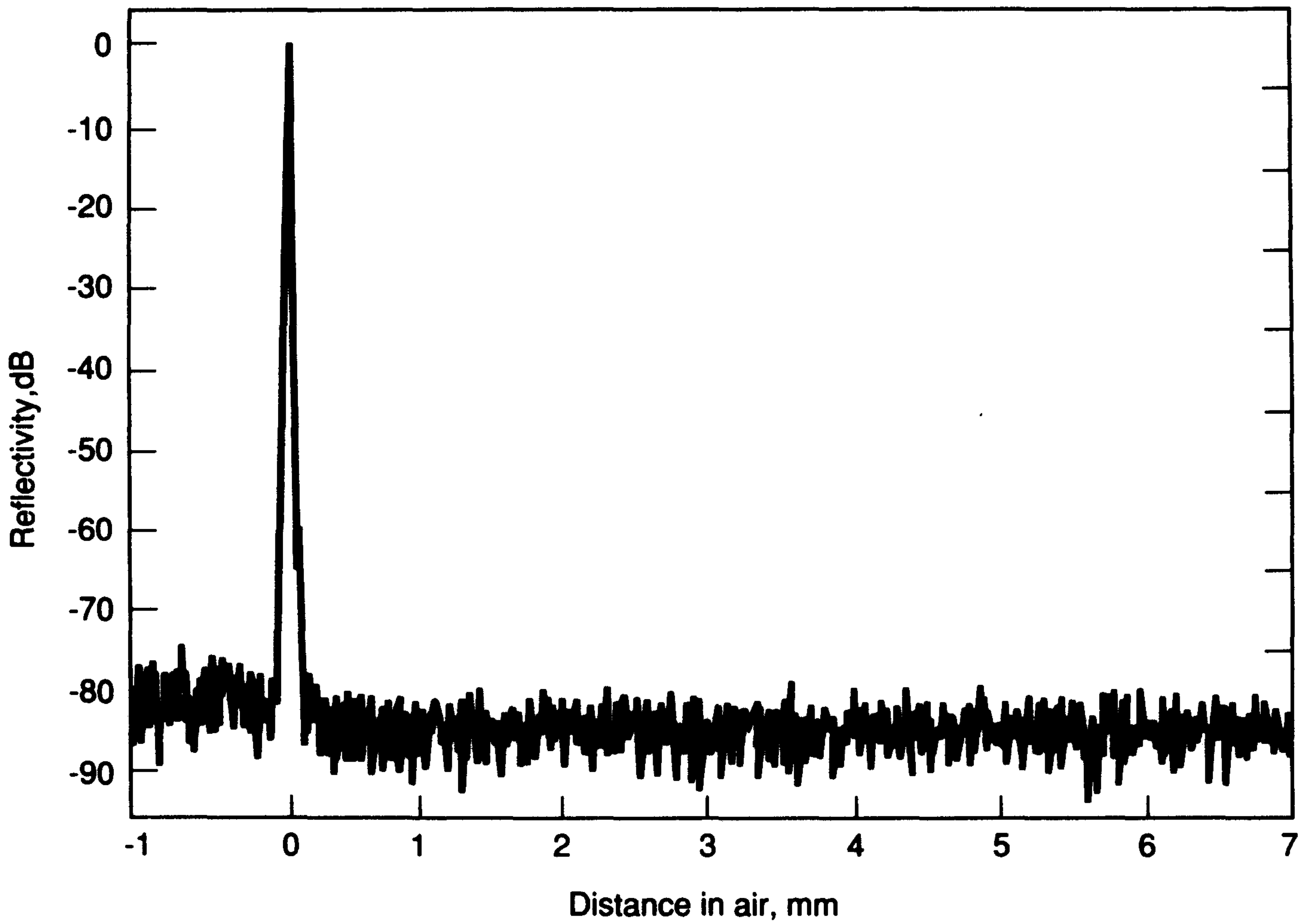

Figure 4: Adding a multi-layer antireflection coating to the front facet of the EELED reduces all reflection signals by an additional 25 to 30 dB. No reflection signals are observed down to the noise floor, below -80 dB. The back facet signal is estimated to be -110 dB or lower for -4 V absorber bias.