Temperature-induced beam steering of Y-coupled quantum cascade lasers

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Abstract. The deflection of the laser beam is achieved without any additional components such as optic or mechanic systems. This is done by injecting additional direct current into one of the two emitting branches, locally increasing the temperature. We estimate that the required temperature difference between left and right branch is approximately 12 K to achieve 2° of beam steering

Keywords: beam steering, quantum cascade laser, coupled wave guide
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INTRODUCTION

Since their first demonstration[1], quantum cascade lasers (QCLs) have been established as high power coherent light sources in the mid-infrared (MIR) and Terahertz (THz) regime of the electromagnetic spectrum with attractive features such as freely designable emission wavelength, continuous wave and high temperature operation. Thus, they are used in a wide range of applications such as spectroscopy, sensing and optical imaging.

Beam steering is desirable to achieve the physical alignment of the emitted radiation pattern with external optical systems for various laser applications. In general, most technologies for beam steering of lasers rely on opto-mechanical systems involving mirrors and lenses driven by motors.[2] However, compared to electrical beam steering, opto-mechanical beam steering is relatively bulky, heavy, noisy and complex. We previously demonstrated coherent Y-coupled cavity (YCC) QCLs emitting at 10.5 µm wavelength operated in pulsed mode.[3,4] Now we show electrical beam steering induced by injecting additional direct current (DC) into one of the two emitting sections of YCC QCL.[5]

SIMULATION RESULTS

Figure 1 shows a double-slit-like simulation where beam steering is induced by a phase difference between the two slits. Then, we calculated the interference pattern in the far field and were able to reproduce the beam steering phenomenon by varying only the phase difference. In order to achieve the arbitrary phase difference between two the branches of YCC QCL, a different temperature in each branch is generated by an additional DC injection in one of two branches. In this case, the induced temperature difference changes the effective refractive index, and also the phase of wave guide modes.

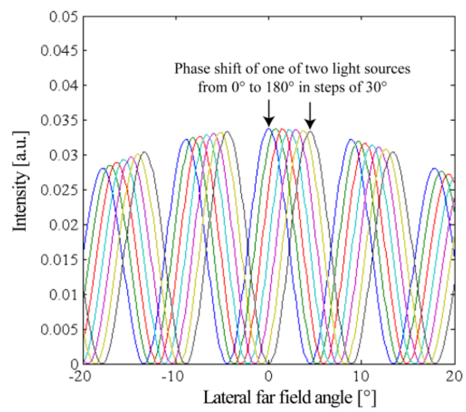

Figure 1 Beam steering simulation by an arbitrary phase shift between the two light sources.

Figure 2 shows result of two-dimensional steady-state heat transfer calculations at the central section of the YCC QCL. The two ridges are situated on a 350 µm thick wafer and separated by 60 µm. At a constant heat sink temperature $T_{\text{heat sink}}$=78 K, the heat source in the active region of one of the two branches is set to 2.54×10^7 W/cm^3. The temperature distribution is then modeled based on Fourier's law of heat conduction $\dot{Q} = -\kappa\nabla T$, where ∇T is the temperature gradient and κ=1 Wcm^{-1}K^{-1} is the thermal conductivity. The

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calculated value of temperature increase in the active region is roughly 18K where 100mA additional DC is injected and the temperature difference between the two branches is about 12K/100mA.

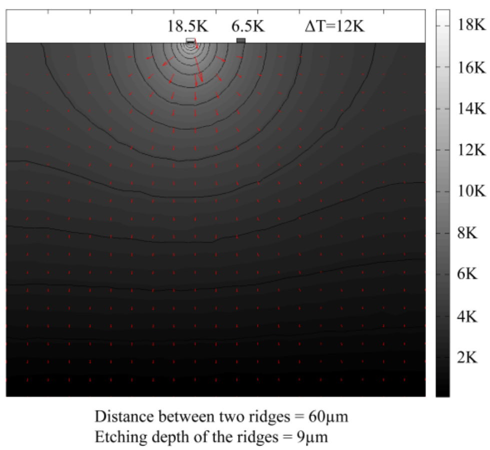

Figure 2: Heat transfer calculations at the central section of the YCC QCL.

Figure 3 shows the temperature difference between two ridges as a function of the etching depth of the ridge. The deeper etching depth shows the bigger temperature difference due to the increase in the heat transfer path. A bigger temperature difference is favorable to increase the beam steering range.

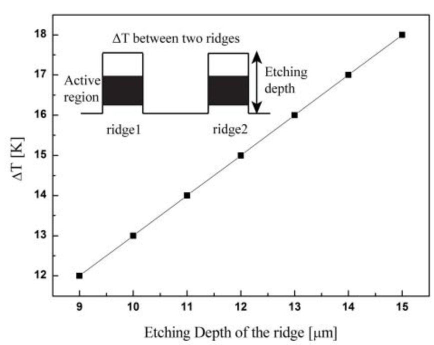

Figure 3: Temperature difference between two ridges as a function of the etching depth

EXPERIMENTAL RESULTS

Figure 4 shows our experimental result where interfering beams are steered in the far field. The arrows indicate the direction of the deflected beams. The observed degree of the beam steering is ±2˚ with an additional 100 mA DC applied. The inset shows the shape of the YCC QCL and the state of the DC current injection. They are steered toward the branch in which the temperature is increased because the phase-shifted beams emitted from one of the two facets modify the spatial position of constructive and destructive interference null in the far field. The degree of coherence between two emitting beams is directly related to the measured interference visibility V in an interferometric superposition $V = (I_{max} - I_{min}) / (I_{max} + I_{min})$ where I indicates the intensity of interfering beams. The interference visibility, in the DC range of 0 to 100 mA, is decreased roughly from 0.88 to 0.84. This indicates the coherence rate is decreasing with the power difference between the two waveguides, however, in the worst case, a reduction of only 3% is observed.

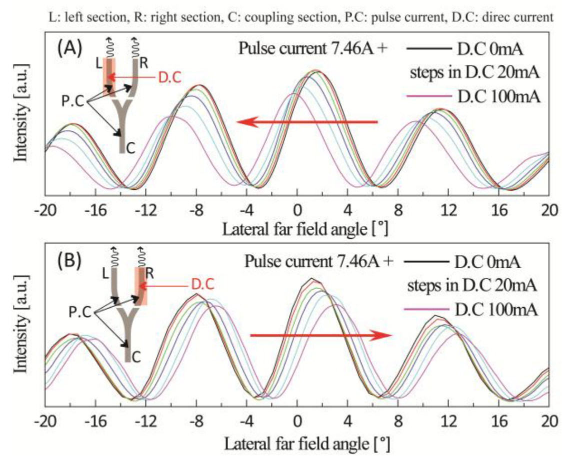

Figure 4: Experimental result of the beam steering at far field by driving additional DC

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