Predicting the divergence of quantum cascade lasers by simulation

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The divergence of a quantum cascade laser beam strongly depends on the shape of the active region. But the divergence can only be measured at the very last stages of packaging the laser. In order to predict the divergence at an early stage, the far-field is simulated by finite element method by extracting the active region's dimensions and shape. To validate the simulation, the far-field of this same laser is measured.

Initial situation and goal

Quantum cascade laser (QCL) has the unique ability to emit at a specific narrow-band wavelength that can be selected by engineering the sequence and thicknesses of the different layers composing the active region. The typical emission wavelength is in the range of 3 to 25µm. Since many molecules have their absorption lines in this range, QCL are especially suited for spectroscopy. However, like all edge emitting semiconductor lasers, QCL has an important divergence, which is strongly dependent on the shape of the active region. The shape varies from laser to laser due to wet etching in the QCL production process. The divergence of a QCL can only be measured in the last steps of assembly, which can last several weeks, only to find out that it is out of specs. The goal of this thesis is to shorten this time-load by predicting the divergence of QCL by simulation.

Methods

This goal can be achieved if the shape and dimension of the active region are known. This is done by overlaying a binary mask over a microscope image of the front facet of the laser. The mask has in its center the approximate shape of the active region. The best fit between input image and mask is achieved when the sum of the differences between their intensities at each pixel is the smallest. This minimum is reached using a basin-hopping optimization algorithm. With the known dimensions of the active region, a 2D simulation of the electromagnetic wave equation can be run and the divergence calculated. However, this theoretical result must be compared with the real far-field of the laser. This is done with the help of a scanning detector, which moves in a spherical motion around the laser positioned in the center of the sphere.

Results

The basin-hopping algorithm in combination with a mask is very well suited for the extraction of active region dimension. With this piece of information, the measured and simulated far-field can be well compared. The final result is a precise prediction of the divergence of QCL. It means that, at an early stage, the useless and useful lasers can be separated.

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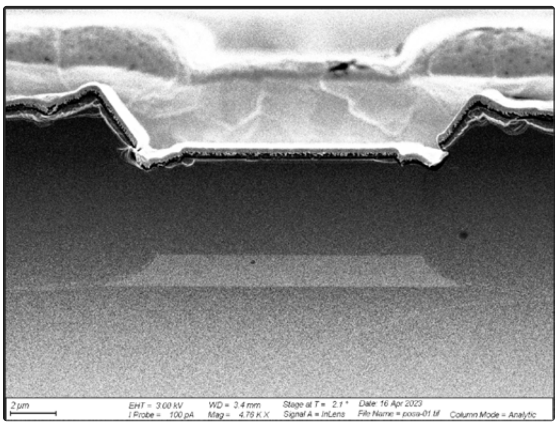
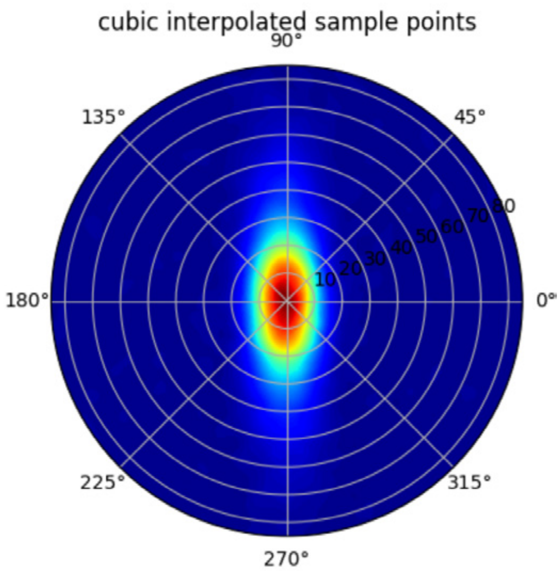


Scanning electron microscopy image of the front facet with the active region in light gray.



Resulting interpolated measurement of the laser's far-field.