Coherent imaging and sensing using the self-mixing effect in THz quantum cascade lasers

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We present recent advancements in the development of coherent THz imaging and sensing systems that exploit the self-mixing (SM) effect in quantum cascade lasers (QCLs). SM occurs when radiation from a laser is partially reflected from an external object and injected back into the laser cavity. The reflected radiation interferes ('mixes') with the inter-cavity field, producing variations in the emitted power and terminal voltage [1]. Thus, by combining the local oscillator, mixer, and the detector all in a single laser, this technique allows the development of simple, self-aligned systems that can sense both the phase and amplitude of the THz field reflected from samples. We demonstrate the coherent nature of this sensing technique for depth-resolved reflection imaging, whereby the phase-shift induced upon reflection is interpreted in terms of surface morphology of the sample. We will also present an alternative, novel sensing modality based on this self-mixing approach.

The THz QCL consisted of a 10-µm-thick GaAs-AlGaAs bound-to-continuum active-region, emitting at ~2.6 THz, that was processed into a semi-insulating surface-plasmon ridge waveguide. Radiation from the QCL was collimated and focused at normal incidence onto the sample using a second identical reflector [2]. The sample was raster-scanned in two dimensions, and the self-mixing signal monitored at each pixel via the voltage across the QCL terminals.

For depth-resolved imaging the QCL was operated in continuous-wave, just above the lasing threshold, where the laser is most sensitive to the feedback of radiation. At each pixel the sample was scanned longitudinally and the SM interferometric waveform recorded over several periods. Each of these waveforms was then fitted to a three-mirror model [3, 4] that describes the laser system under feedback, as shown in Fig. 1. The phase parameter in this model can be equated to the distance travelled by the THz radiation in the external cavity, and hence to the depth of the surface of the sample. Figure 2 shows an exemplar cross-section of a stepped GaAs structure fabricated by wet chemical etching. As can be seen, the etched steps can be resolved, as well as the tilt of the sample, which is estimated to be ~0.4º. Figure 3 shows a three-dimensional profile of a similar structure.

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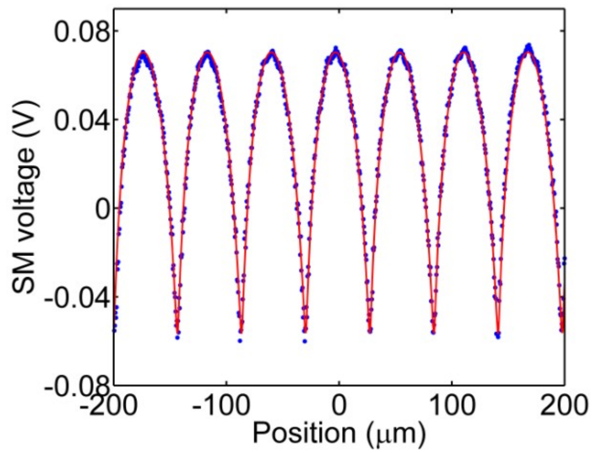

Fig. 1: Exemplar self-mixing waveform obtained by longitudual displacement of the target. The dots are data points, the solid line represents a fit to the data.

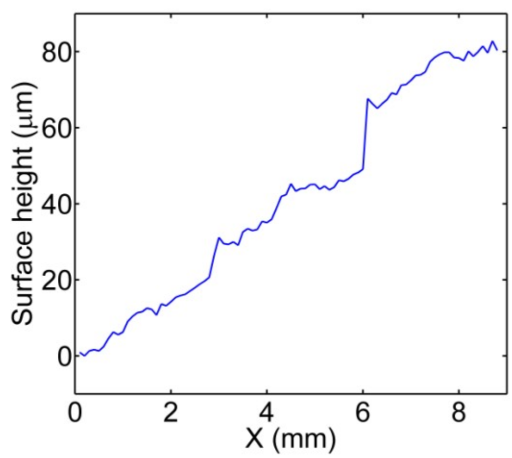

Fig. 2: Cross-section of a GaAs sample revealing etched steps and sample tilt.

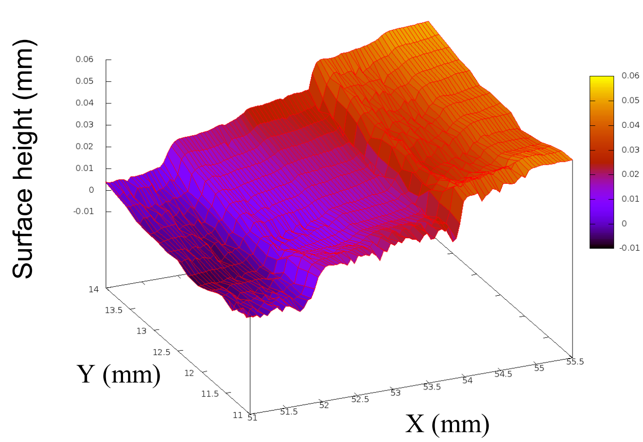

Fig. 3: Three-dimensional image of a stepped GaAs sample