Silicon based micro-optical collimating element for mid-infrared Quantum Cascade Lasers

Lubos Hvozdara (1), Eric Logean(1), Joab Di-Francesco (1), Hans Peter Herzig (1), Reinhard Völkel (2), Martin Eisner (2), Pierre-Yves Baroni (3), Michel Rochat (3), Antoine Müller(3)

1 : Institute of Microengineering at EPFL, Bréguet 2, 2000 Neuchâtel Switzerland
2 : SÜSS MicroOptics, Rue Jaquet-Droz 7 CH 2000 Neuchâtel Switzerland
3 : Alpes Lasers S.A., Passage Max de Meuron 1 – 3, 2000 Neuchâtel, Switzerland.

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Abstract: A realization of a high numeric aperture, aspheric, silicon based collimating element for the mid-infrared (4 – 14 microns) Quantum Cascade Lasers, suited for mass production using computer driven reactive ion etching is presented.

1. Introduction

Mid infrared (4-20 microns) technology marked considerable progress in the last two decades, mainly due to the advent of Quantum cascade lasers in 1994 [1]. The industrial potential of this technology however depends on the availability of all necessary optical components like lenses, waveguides, gratings and anti-reflection coatings. The properties of the mid – infrared light requires use of special materials, and a different approach as compared to the visible or to the near infrared technology. There are several producers of mid-infrared optics offering their products in the market, however, the methods of their fabrication and the use of materials they propose are limiting the price at relatively high levels, restrictive for the low cost applications needed for mass proliferation of the mid-infrared technology.

In this contribution, we present a realization of a aspheric collimating element matched to the typical emission pattern of a quantum cascade laser. There was a requirement from industrial partners for designing the element to match the limits of their proprietary fabrication process DRIE facilitating a mass production of the elements.

2. Design

The emission of a quantum cascade laser is strongly divergent (Fig. 1) exhibiting 40° of divergence in the horizontal axis and 60° in the vertical axis. The targeted divergence is in the range of 6 mrad. The fabrication technology applies several restrictions – mainly the diameter of the lens can not exceed 2 mm and the maximum apex height must be kept below 200 microns. The material used for the lens realization is optical grade silicon with refractive index in the range of 3.4 – depending on the wavelength. The design shall cover the wavlenegth range from 4 to 8 microns, and should still work at lower wavelengths (sacrifising a part of collection efficiency).

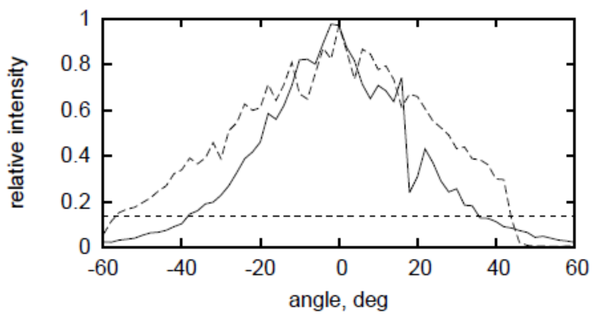

Fig. 1 A cross section of a measured emission pattern for a Quantum cascade laser. Dashed line stands for vertical axis, the solid line for horizontal axis.

Using the given parameters the lens has been designed. It follows the simplest aspheric profile with a conical correction defined by the formula (1) where c is the curvature, r- distance from the optical axis, and k is the conical constant. The lens is designed with a thick body 3 mm long, resulting in the conical constant of k= -1.742.

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} \quad . \ (1)$$

The resulting lens profile of the lens with 2.45 mm diameter and apex height if 0.198, including the aspheric correction is shown in Fig. 2. The minor deviation from the spherical surface has been identified as suitable for the fabrication technology using DRIE.

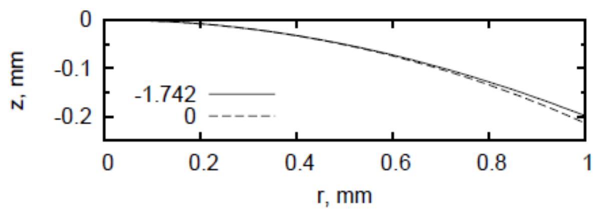

Fig 2. Lens profile: dashed line – spherical design, solid line: aspheric conical correction applied.

The final design of the lens has been ray-traced using a commercial software and the optical properties have been verified. A numerical aperture of 0.863 and working distance of 150 microns have been determined.

3. Realization and tests

Samples of the designed lens have been realized on wafer level using a proprietary technology of controlled reactive ion etching on wafer level. The body of the lens has been realized by wafer bonding in order to achieve the desired thickness and the chips, sized 2.2*3.2 mm^2, have been diced (Fig.3). The surface roughness below 50 nm RMS has been measured and the measuredn lens curvature has been kept below 2 % of across all the lens profile.

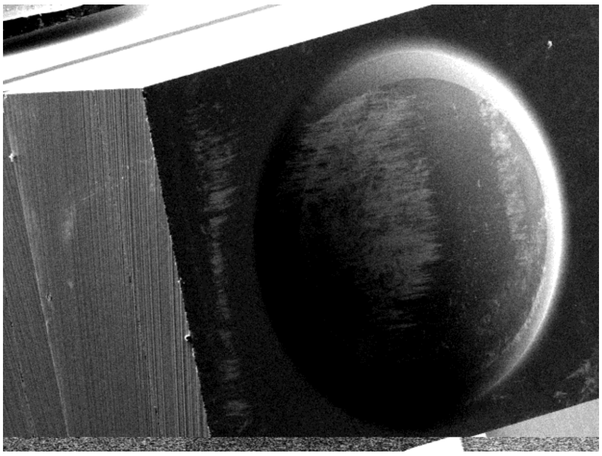

Fig. 3 SEM Picture showing a sample of a realized lens.

The lenses have been tested using a series of quantum cascade lasers, at different wavelengths using a beam profiler. A typical image recordedd at a distance of 0.6 meters is shown in fig. 4. The analysis reveals a conservation of a Gaussian profile and a divergence of a 7 mrad in the vertical (more divergent) axis.

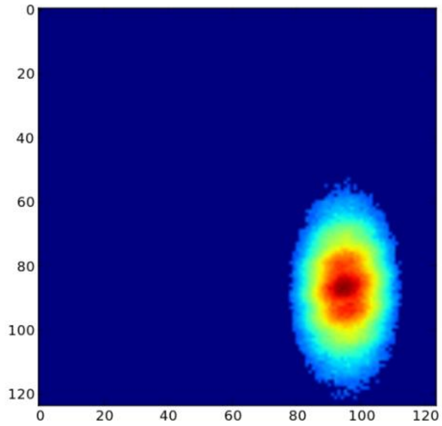

Fig.4 A beam profiler record of a quantum cascade laser emission at 11.2 micron emission wavelength recorded at 60 cm from the lens.The horizontal fringes modulated on the signal are attributed to the Fabry-Pérot resonance in the window of the bem profiler.

4. Conclusions

We have designed and realized a DRIE etched microlens matched to the emission patter of quantum cascade lasers. Owing to the used technology the lens is suitable for mass production. The numerical apperture NA = 0.863 has been realized and the divergence better than 7 mrad has been recorded in the marginal conditions of operation at the wavelength in the range of 11 microns. The following activities in this directions are oriented towards the development of a broadband antireflection coating, finalizing the development phase of the lens conception.

5. References:

1) J. Faist, F. Capasso, D. Sivco, C. Sirtori, A. Hutchinson, and A. Cho, Science 264, 553 (1994)