Beam-shaping for a LIDAR System for Urban Scenarios

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***Abstract*—Automotive LIDAR sensors are generally considered as enabling technology for higher-level autonomous driving. Different concepts to design such a sensor can be found in the industry. In the course of an Austrian research project, a MEMS based LIDAR system for automotive applications is currently developed and within this paper we describe the overall system concept and, in some detail, the requirements and the design of the emitter optics which turn out to be rather complex, in order to enable the sensor to detect objects of about 10 cm x 13 cm size at a distance of 80 m and a field-of-view of 20° x 90.**

***Keywords*—LIDAR; MEMS; scanner; beam shaping.**

I. INTRODUCTION

Light detection and ranging (LIDAR) is arguably one of the key components for future autonomous driving and there is much interest in developing robust, compact and price-effective solutions. Consequently there has been a lot of research in recent years [1],[2],[3],[4]. Among different scanning technologies, Microelectromechanical Systems (MEMS) scanning mirrors provide unrivalled advantages in terms of size, speed and cost over other types of laser scanners, making them ideal for LiDAR in a wide range of applications [5].

Current Advanced Driver Assistance Systems (ADAS) focus on comparatively simple scenarios with objects behaving in predictable ways, such as highway traffic or parking assistance without pedestrians, cyclists or transversal traffic. Yet, there is an urgent need to extend ADAS and Automated Driving (AD) to handle urban traffic scenarios. Also, the 'European new car assessment programme' now defines test cases that involve Vulnerable Road Users (VRUs) such as adult pedestrians, children and cyclists in urban scenarios [6].

For complex scenarios, like urban traffic, high resolution and large field of view is a key requirement, which is challenging to achieve. The Austrian project "Integrated LIDAR Sensors for Safe & Smart Automated Mobility" (iLIDS4SAM) addresses this issue by developing a novel LIDAR-based system for predictive assessment of hazardous situations involving VRUs in an urban setting [7]. Within this project a compact LIDAR system, based on a MEMS scanner mirror is developed.

The remaining of the paper is structured as follows. Section II presents the general concept of the ilids4sam-LIDAR. In Section III we describe in detail the emitter-optics and, finally, in Section IV provide a short summary and outlook.

II. CONCEPT

As outlined above the targeted scenario of urban traffic necessitates high resolution, large field of view and robust operation under ambient light conditions. The target specifications, we deduced for the LIDAR system, are listed in Table 1.

TABLE 1: TARGET SPECIFICATIONS OF THE LIDAR SYSTEM

Quantity	Target-specification
Wavelength	905 nm
Field of view	60° x 20 °
Distance	Up to 80 m
Resolution	<0.07° (≙ 10cm@80m)
Depth resolution	30 cm
Framerate	25 fps

The key component of the LIDAR is a 1D MEMS scanner mirror [8], which is electrostatically actuated. In its latest generation, the MEMS features a mirror-diameter of 5 mm, a mechanical amplitude of the tilting angle of 10° (corresponding to an optical scanning range of 40°) and a frequency of 2 kHz.

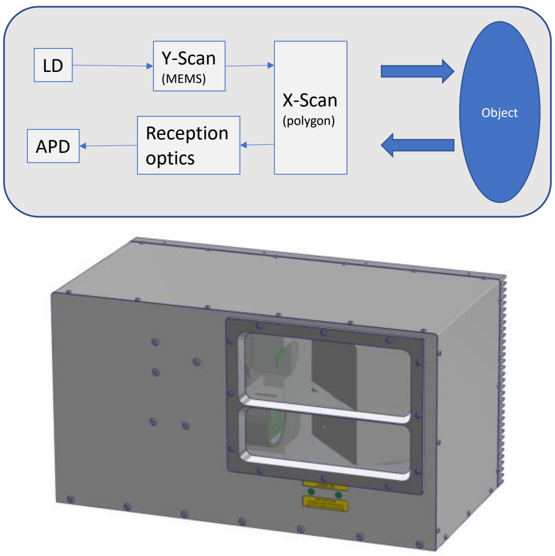

Fig. 1. Overall system concept and design of the full system.

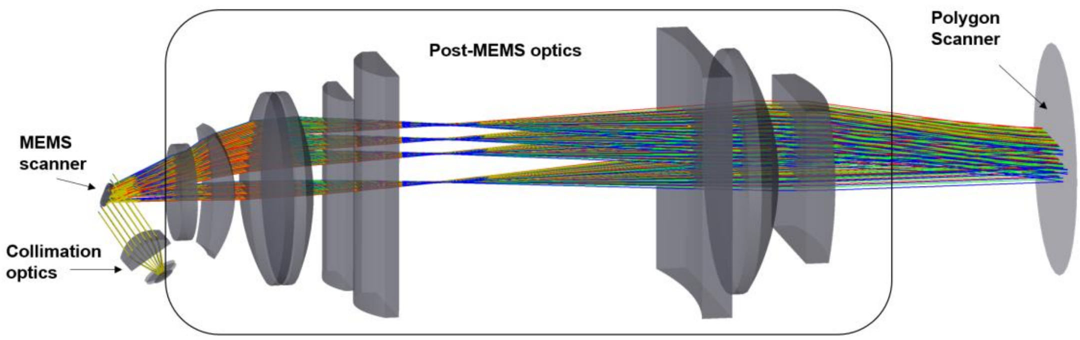

Fig. 2: Optical layout of the LIDAR emitter optics comprise a collimation of the laser diode stack, the MEMS scanner mirror and a multi element lens for beam shaping.

The concept foresees that the beam is scanned via this MEMS in one direction, while the second dimension is scanned via a subsequent larger polygon scanner. This approach enables scanning of the required field of view and use of a large second scanner enables high collection efficiency of the back scattered light in the corresponding dimension. Thus, for one dimension, the light collection can be performed behind the scanning optics, which significantly reduces background light levels on the detectors, because only back reflected light is detected. Thus, rather than observing the whole scene, the detector channel only detects a line, strongly improving signal to noise, in particular, for the (realistic) situation of strong background from sunlight.

Since LIDAR is based on measuring the backscattered light system, the measurement time for an individual point cannot be arbitrary short for long range LIDAR based on pulsed time of flight (e.g., a minimum waiting time of ~0.5 µs is required for 80m distance). Therefore, it would not be possible to measure the required point-cloud with the specified density and framerate by pure point-scanning. Some way of multiplexing is required. While in previous realizations, relying on pure 1D scanning, a vertical line was scanned and detected with a linear detector array, here we follow a hybrid approach and scan in two dimensions, albeit still the measurement is multiplexed by projecting a line, which is detected on a line-detector with 16 APDs.

While this paper focuses on the beamshaping, performed in the emitter branch, a more detailed description of the overall LiDAR system can be found in [9]. Most relevant for this presentation are the resulting requirements for the scanned laser beam. Besides ensuring that the whole FOV is scanned as efficiently as possible, there are stringent requirements on the beam-profile. The beam should ideally feature a top hat profile in the form of a thin line, with minimal vertical divergence, but an accurately defined horizontal divergence with a full width of 1.5°.

III. Emitter Design

The crucial part of the overall LIDAR system, is the design of the emitter optics which have to fulfill the following requirements:

- Collimation of the laser diode bar to a beam with well-defined asymmetric divergence.
- Fine calibration of the field of view of the sensor since the mirror maximal amplitude does not well correspond to the whole FOV.

Simulations were performed using Zemax, Opticsstudio.

The overall optical layout is shown in Fig. 2. It consists of sub-units, namely the laser diodes and first beam collimation, the MEMS scanner mirror, which scans the beam in one dimension and subsequently beam shaping optics to generate the required characteristics, before hitting the second scanner device, which is a rotating polygon mirror. These elements are shortly outlined in the following.

A. *Collimation*

The laser diode is a stack with 8 emitters with a pitch of 400 µm and each consisting of 3 epitaxially stacked emitters, resulting in three stacked lines in the emission profiles.

Collimation of this stack is done using a cylindrical lenslet array placed at a distance of 1mm in front of the emitting facets for slow axis collimation and, a fast axis collimation, placed at a larger distance, for beam collimation of the vertical axis, where small divergence is required.

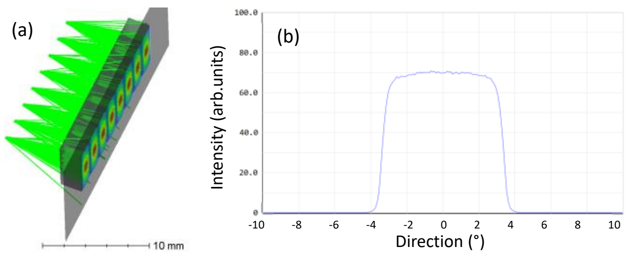

Fig. 3: (a) laser diode with a cylindrical lenslet array for slow axis collimation, (b) angular profile of combined beam in slow axis

As shown in Fig. 3, in this configuration we can achieve a nearly perfect top-hat-profile in angular space for the slow axis collimation. The divergence still has to be reduced by a factor of 4 in order to achieve the targeted divergence of 1.5°. This step is performed by telescope-optics after the MEMS.

For fast axis collimation an aspheric lens with a focal distance of 4 mm is used, in order to collimate the beam in the vertical axis.

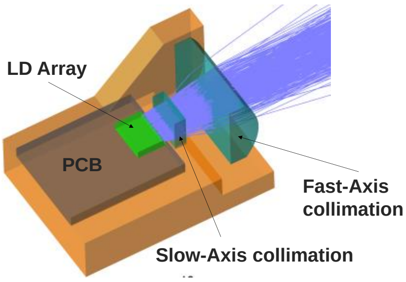

Fig. 4: 3D sketch of the laser diode collimation.

A sketch of the arrangement of the laserdiode bar and the cylindrical collimation optics is shown in Fig. 4 and Fig. 5 shows the beam profile, which is obtained after collimation directly in front of the MEMS scanner.

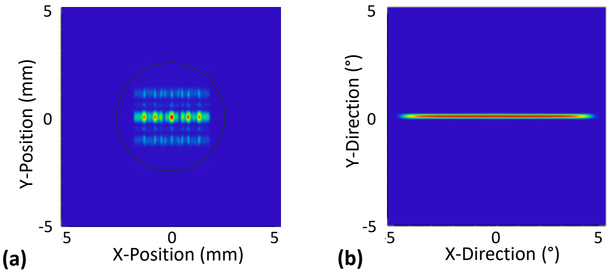

Fig. 5: Beam profile directly after collimation before the MEMS mirror: (a) intensity distribution (b) radial distribution

B. *MEMS*

The MEMS mirror is an electrostatically driven scanner. It has a diameter of 5 mm, and a mechanical amplitude of +/-10°. It´s resonance frequency is above 2kHz, which makes it very insensitive to mechanical vibrations.

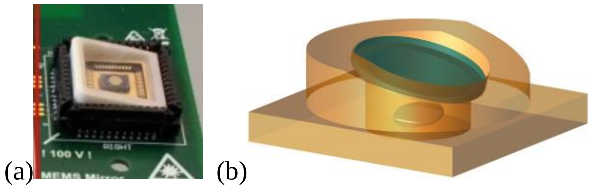

Fig. 6: (a) typical MEMS scanner mirror [4] (b) housing with tilted cap

In the set-up the MEMS is hit by the beam under a small angle of 30° for efficient coverage of the mirror area. Furthermore, it is packaged with a tilted cover window, so that the static reflection from the window does not lie within the field of view of the LIDAR scanner.

C. *Telescope for beam shaping*

Following the MEMS element, we have designed an anamorphic telescope, which provides a magnification of 2x and 4x for horizontal and vertical direction, respectively. This ensures that the field of view generated by the MEMS scanner is reduced from 40° optical scan to the 20°, which are the target value for the vertical FOV. Also, the 4x magnification decreases the vertical divergence of the beam to <0.07°, which matches to the required resolution.

The telescope design (see Fig. 7) includes eight lens-elements. Several simpler designs were also evaluated, but they did not provide sufficient quality.

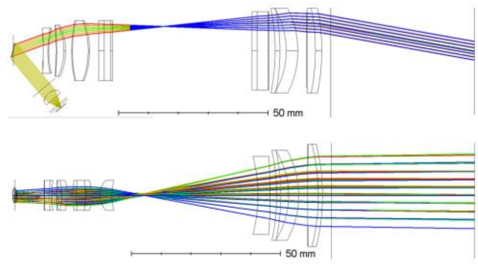

Fig. 7. Side-view and top-view of the optical design of the telescope optics.

As demonstrated in Fig. 8, this design provides the required specifications.

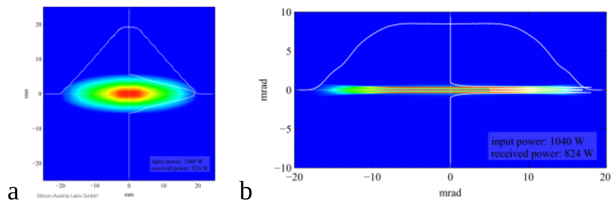

Fig. 8 Beam profile in the (a) nearfield and (b) farfield (Note that for the near-field the spatial and for the far-field the angular distribution is plotted.)

The differences in magnification for the horizontal axis, depending on MEMS tilt angle and y-aberrations due to axes crosstalk are noticeable and partially impact performance. This can be seen in the far field pattern, shown in Fig. 9.

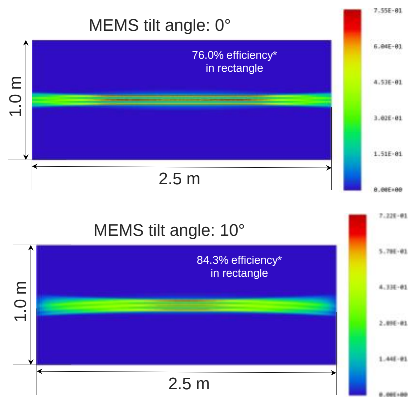

Fig. 9 Far-field intensity distribution at a distance of 80m for mirror tilt angles of 0° and 10°, which is the maximal tilt.

 ISBN: 978-1-68558-091-9

D. *Overall system assembly*

For the first demonstrator system, based on the presented design, we aim for an elegant breadboard style with still a partially adjustable mechanical frame for the optical system, including e.g., translational stages, since tolerances of some of the components are ill defined. Furthermore, we were aiming at the use of standard components as far as possible, rather than pushing towards maximal miniaturization.

Fig. 10 shows a photo of the first assembled emitter unit mock-up, where, however, still some functional components are missing.

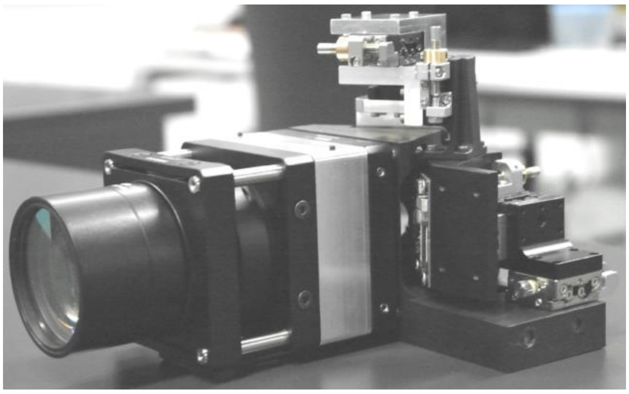

Fig. 10: Picture of the assembled emitter unit, waiting for the final components and electronics.

IV. CONCLUSIONS AND OUTLOOK

We presented an overview of the design of the emitter part for a LIDAR system, which is under development. In the simulations presented we could fulfill all requirements and specifications. The assembly of a demonstrator on the level of elegant breadboard is ongoing and first results from characterization of the emitter unit, as well as the complete LIDAR sensor, are expected in the next months. The complete LIDAR system will be tested in real-word use-cases. Further developments will target miniaturization and a ruggedized and cost optimized version.

ACKNOWLEDGMENT

This work has been jointly supported by the BMK within the program “ICT of the future” under grant agreement no. 878713 (iLIDS4SAM-Project) and by Silicon Austria Labs (SAL), owned by the Republic of Austria, the Styrian Business Promotion Agency, the federal state of Carinthia, the Upper Austrian Research, and the Austrian Association for the Electric and Electronics Industry.

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