FlatVision—Imaging Optics in Confined Spaces

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Because of technological limitations, miniaturizing imaging systems below the milllimetric scale is highly demanding. However, different industries such as medical endoscopes, industrial Quality Control (QC), and micro-robotics are requiring further miniaturized vision systems. CSEM is developing an innovative disposable endoscope based on extra flat flexible polymer slabs used as multimode waveguides. These can be produced with low-cost roll-to-roll production technologies and can be easily customized by patterning, coating and printing techniques according to the specifications of the target application. In order to couple the light (i.e. the image) in and out of the waveguide, diffractive subwavelength gratings are used. These nano-scale optical structures enable a highly efficient and controlled light trapping by total internal reflection, while minimizing the distortion and scattering due to defect near the edges of polymer slabs.

Continuous miniaturization of vision system is driven by the needs of markets of consumer electronics and medtech. Recent developments includes camera as small as 1 cubic millimeter and stereoscopic camera module as small as 2.2x1x1 mm [1]. Further miniaturization of silicon image sensors, such as CMOS and CCD, is a complex task due to the material and processes involved. CSEM is developing a new endoscopic vision sensor based on disposable and flexible polymer slabs to address current unmet needs by further miniaturizing imaging endoscopes.

In order to reduce further the size of endoscopes, the light sources and imaging system are left out of the endoscope and a polymer slab is used as a multimode imaging waveguide. The waveguide is used to transport light illumination to the objects and to transport back a part of the light reflected from the objects, the imaging beam, by using total internal reflection. Polymer slabs thinner than 200 µm, could be tested and validated as a fully functional endoscope, illuminating and imaging objects at the same time.

In order to couple the illumination and the imaging beams in and out of the polymer slab, extremely flat (< 1 µm) diffractive optical couplers are used. The diffractive optical couplers are made of subwavelength gratings [2] that can be totally embedded in a polymer matrix. They can be nano-patterned on the polymer surface using established techniques (*i.e.* hot embossing, UV casting) that are compatible with industrial high volume production lines.

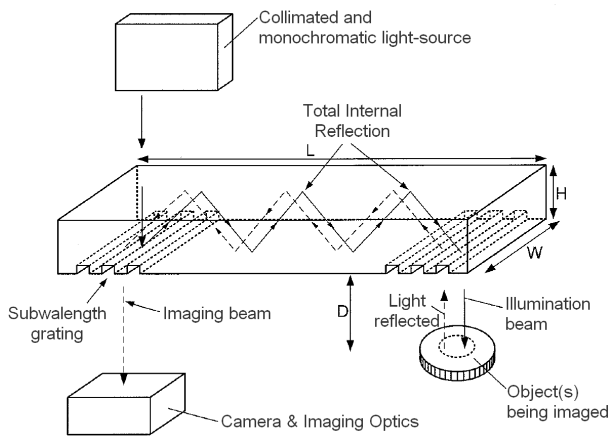

Figure 1: Sketch of a slab waveguide diffractive endoscope.

A sketch of shows the components and the optical path for such a polymer slab endoscope in Figure 1.

The distinctive features of these innovative endoscopes are i) the possibility to achieve an endoscope thickness below 200µm, ii) the ability to record lateral images in confined spaces, iii) the ability to image samples (e.g. biological tissues, objects) in direct contact with the polymer slab, with no minimum imaging distance, and iv) the compatibility with high volume fabrication techniques that can enable the cost-effective production of disposable endoscopes.

A first implementation is a flat line-scanning endoscope acquiring a sequence of 1D images by a scanning movement, with which 2D images are reconstructed by software stitching. The first images acquired with polymer slab thinner than 200µm with an aspect ratio above 150 (L>150*H) exhibits a resolution below 100µm. Such a thin polymer waveguide with its diffractive coupler and an example of acquired image is shown in Figure 2.

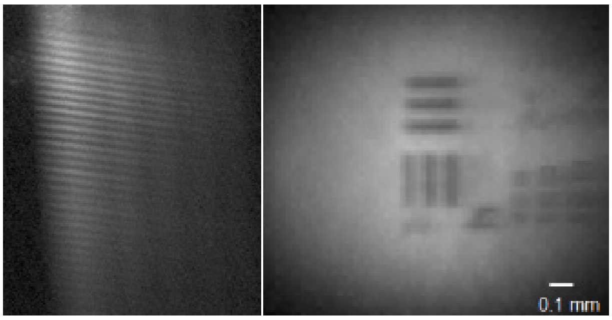

Figure 2: Left: 1D image of an optical target with thin horizontal lines. The thickness of the individual lines is below 100 µm. The thin polymer foil used as an illumination and imaging waveguide is thinner than 200µm (H<200µm). Right: Example of 2D image acquired with a diffractive endoscope of a test target reconstructed by stitching 1D images.

These results are highly promising, for example for the development of ultra-thin disposable endoscopes made of thin polymer slab waveguides, having the bulky light sources and imaging system out of the confined spaces being imaged. First prototypes having thicknesses below 200µm exhibit good optical resolution. A fully automated 2D scanning endoscope is currently being developed and tested in various medical and industrial applications

[1] NanEye camera from CMOSIS are in pre-production when this article is written. Intra-heart endoscopy during surgery was demonstrated: www.youtube.com/watch?v=KwfknUbpGcg

[2] Patent applications WO2015062641 & WO2014016343