HIGHLY FLEXIBLE ENDOSCOPE MADE OF SILICONE

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Objective

At present, during medical examinations of small tubes, e.g. the ear canal, glass fiber endoscopes are being used for optical imaging. Unfortunately, these glass fiber endoscopes are too rigid to be inserted into the tuba auditiva without causing any pain and may lead to injury and a chronic inflammation of the middle ear.
A soft and highly flexible endoscope would solve these problems, avoid the currently common tympanoscopy operations being performed only for diagnostic purposes, and allow for an ambulant diagnosis of the middle ear and the Eustachian tube for the first time.

Concept

In figure 1, a sketch of the distal end of the silicone endoscope is shown. The endoscope consists of a waveguide matrix (1), a lens system (2), a transparent protective layer (3), a light isolating layer (4), and a layer system of high refractive index silicone (6) and low refractive index silicone (5+7).
The examination area in the interior of the body can be illuminated by an external cold LED source whose light is guided in layer 6 due to total reflection at the surface of the layers 5 and 7.
An isolating layer (4) prevents the illuminating light from overcoupling into the waveguide matrix (1). The matrix guides the weaker signal that is reflected from the body to a detector outside. For manufacturing reasons, the lens and the waveguide matrix are coated with a low refractive index silicone (3) before being covered by layer 4. The lens system (2) focusses the image on the waveguide matrix (1). Each of the ribs (10) of the waveguide matrix (1), cf. figure 2, transmits one pixel. The reflected signal is transmitted inside the waveguide matrix again due to the principle of total reflexion. The light is guided in the high refractive index silicone (8), the lower refractive index material (9) functions as cladding.

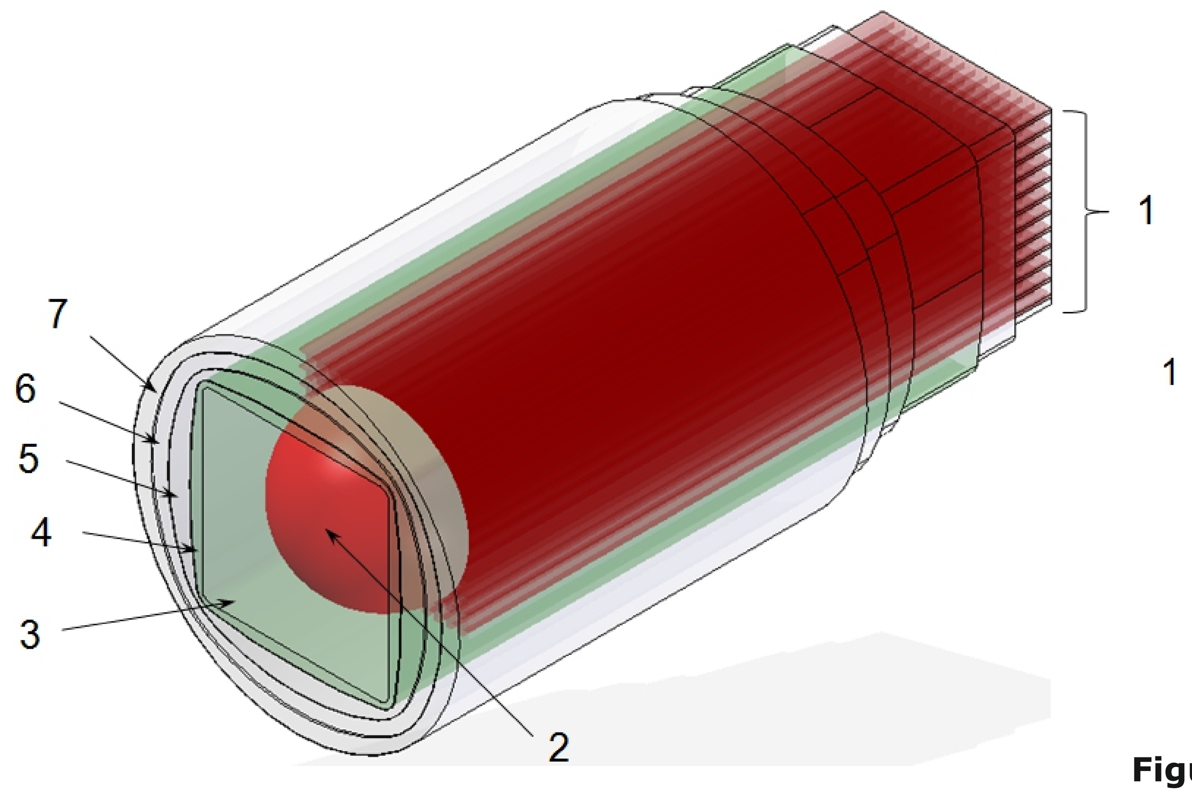


Figure 1: Sketch of the distal end of a silicone endoscope.

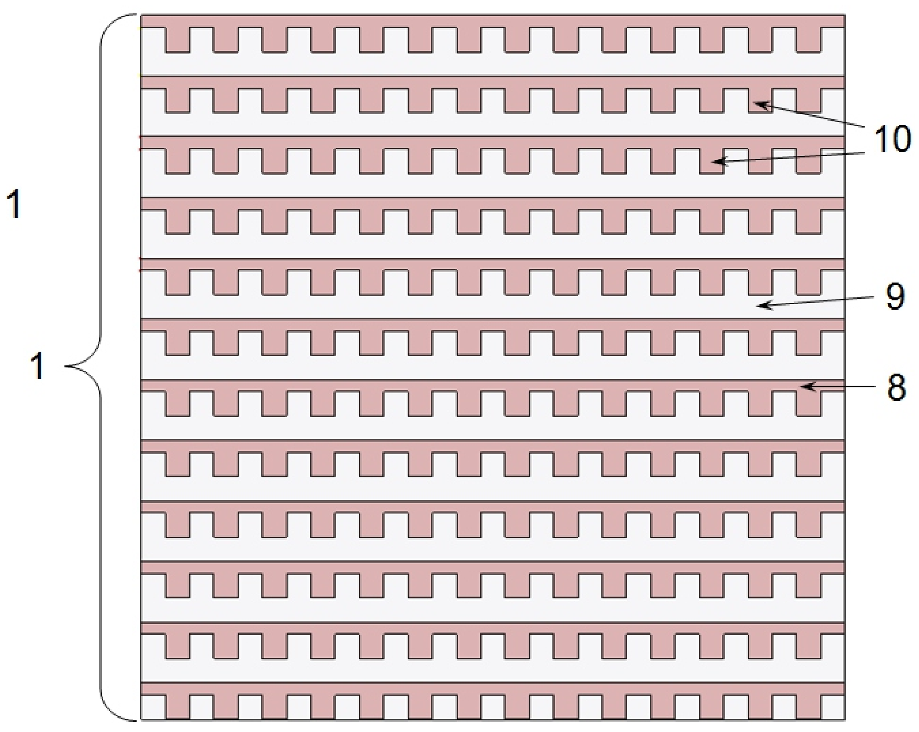
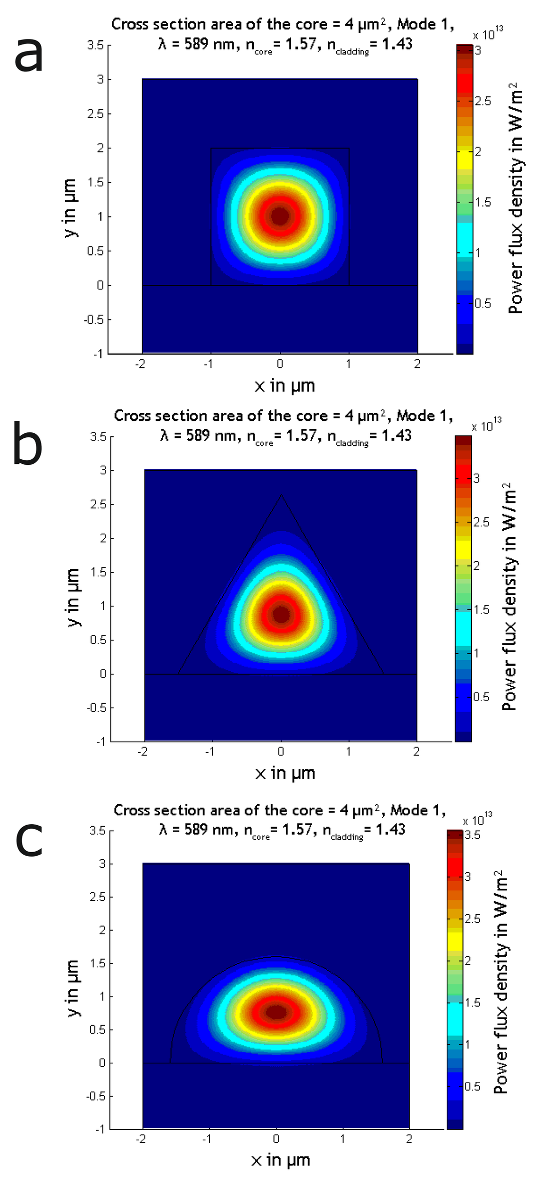


Figure 2: Cross-section of the waveguide matrix. Each of the ribs (10) of the high refractive index silicone (8) forms a pixel. The low refractive silicone layers (9) act as optical isolating areas for accurate light transmission.

Simulation



In order to find the best geometry for the wave guides, the light propagating behaviour in cores of different sizes and shapes was investigated, using the simulation tool Comsol. The simulations reveal that the core size should be at least 2x2 μm² for the chosen optically highly transmitting silicones with refractive indices $n_{core}=1.57$ and $n_{cladding}=1.43$. This size allows for an almost 100% transmission of 33 modes of light with a wave length of λ=589 nm (red light, the dominating colour in the middle ear). Furthermore, the shape of the core (quadratic, triangular or semi-circular) is not significant for the chosen core size of 4 μm², the values for the power flux density lie in the same range for all shapes.

Figure 3: Power flux density distribution of the first mode in a quadratic (a), a triangular (b) and a semi-circular (c) core. All cores have a cross-sectional area of 4 μm². Simulation with Comsol, λ=589 nm.

Manufactoring techniques

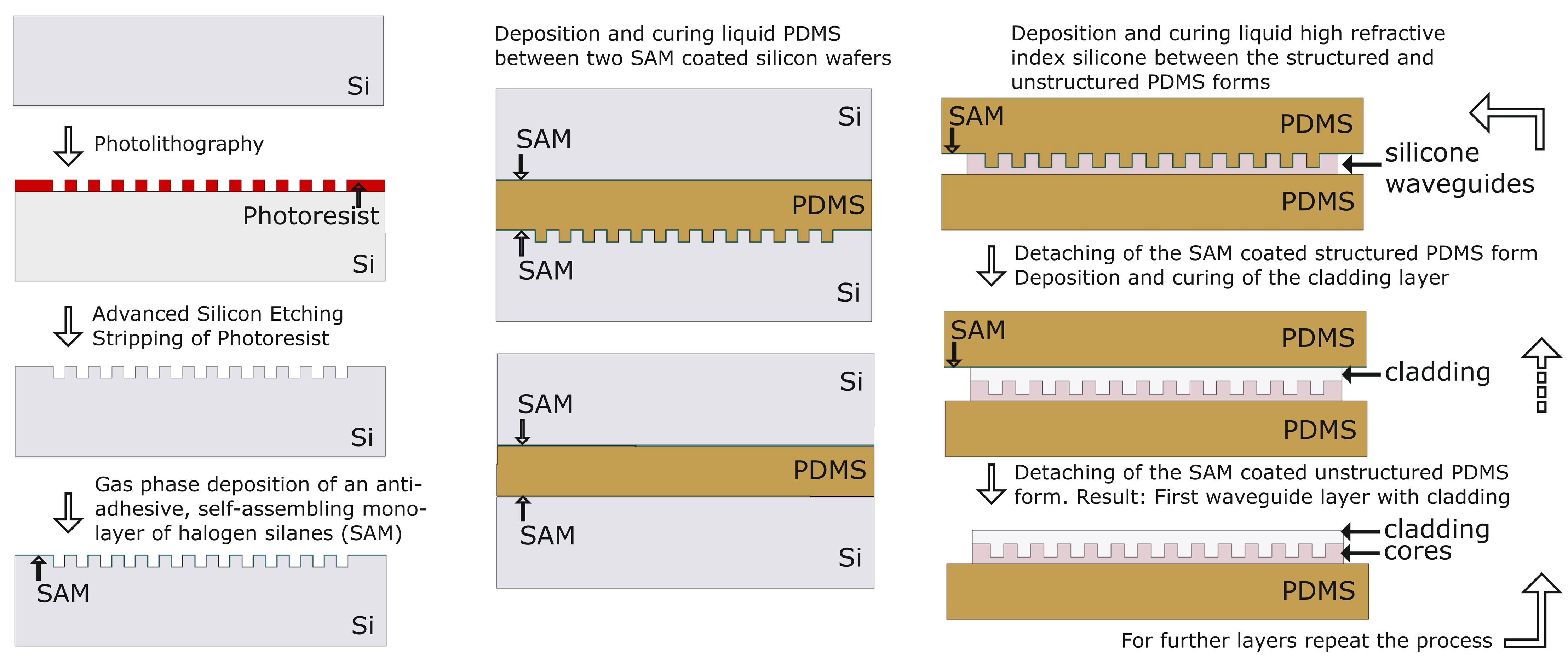


Figure 4: Sketch of the manufactoring process of the first waveguide matrix layers.

Results

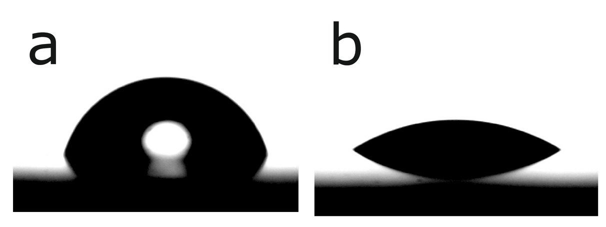


Figure 5: Cured silicone drops on SAM coated silicone (a) and SAM coated silicon (b).

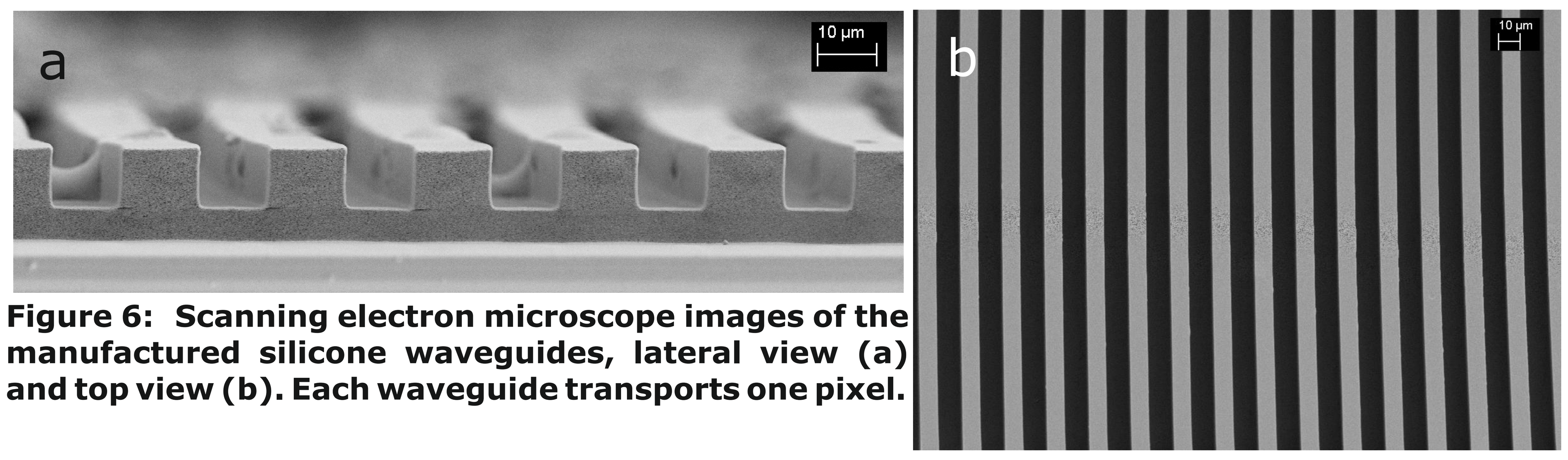


Figure 6: Scanning electron microscope images of the manufactured silicone waveguides, lateral view (a) and top view (b). Each waveguide transports one pixel.

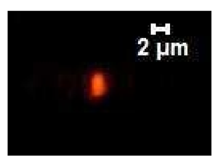


Figure 7: The transmitted signal of a HeNe-laser source inside a silicone waveguide, detected by a CCD-camera

The first silicone layers have been successfully manufactured, cp. figure 6, using the pressing and curing tool showed in figure 8. Currently, the 100 layer matrix is fabricated. The silicone lens has been realized by placing drops on different substrates coated with a monolayer of halogen silanes (SAM), cf. figure 5.
In figure 7, the transmitted signal of a HeNe-laser source inside a single waveguide is shown. First measurements of 5 mm long waveguides show no detectable loss.

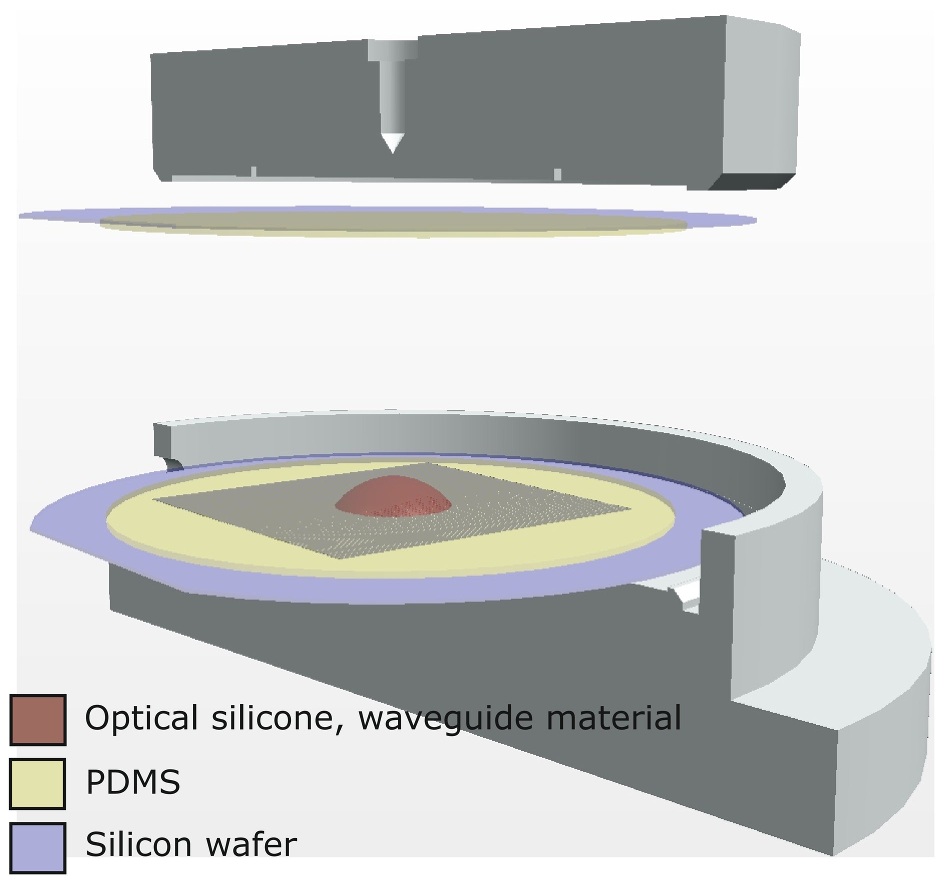


Figure 8: Pressing and curing tool for waveguide fabrication

Outlook

A soft endoscope made of silicone would be a great help in the medical diagnostic field and could soon be part of the standard equipment of otorhinolaryngologists. Furthermore, it could be used as a positioning help in cochlear implant operations, tube dilatations and other medical applications. Beyond the medical field, it is also interesting for microfluidic, biological and industrial applications, where small and difficult to access areas need to be observed.