Combining organic lasers with optical waveguides and microfluidic channels may enable inexpensive, disposable diagnostic tests that can be analyzed at the patient’s bedside.

Lab-on-a-chip devices (LOCs) enable biomedical or chemical tests for point-of-care analysis or screening. Optical sensing promises high sensitivity and the possibility of detection without chemical markers. This will speed up response time and reduce the need for chemicals by skipping the labeling steps commonly used in marker-based approaches.

We are developing optofluidic LOCs for single use as disposable tests. Most current disposable sensor chips are based on a combination of different materials, such as glasses, polydimethylsiloxane, silicon, and polymers. All-organic LOCs offer the advantages of biocompatibility, fabrication flexibility, and low raw-material cost. Our approach aims to create systems from poly(methyl methacrylate) (PMMA) that integrate organic lasers, optical waveguides, microfluidic channels, surface functionalization, and fluorescence excitation on a single chip. We are using mass-production techniques to show the applicability of this approach, by avoiding electrical interconnects and instead relying on optical and fluidic interfaces.

We demonstrated feasibility by combining two consecutive elements of the light path. First, we added organic semiconductor lasers by imprinting a distributed-feedback (DFB) grating into PMMA. We then evaporated a thin film of photoactive material on top of this structure. The lasing wavelength is within the visible-light regime and widely tunable within the gain spectrum of the organic active material. We coupled the emitted light from the DFB laser into polymer-strip optical waveguides, which direct light to a microfluidic channel. Tailored surface functionalization in the channel enables local excitation of fluorescent markers, and thus detection of selected components in biomedical or environmentally relevant fluids.

Figure 1 shows a schematic of the final device: a chip the size of a microscope slide is made from PMMA, comprising a microfluidic channel and optical elements. An external laser diode optically pumps one of three integrated organic DFB lasers. The laser emission is coupled to a monolithically integrated polymer waveguide transferring the light to a microfluidic channel. (For fluorescence detection of dye-labeled biological specimen, lasers are preferable as sensors will benefit from their high excitation efficiency and avoid spectral overlap with the fluorescence-marker emission.)

Organic semiconductor DFB lasers consist of a thin-film active material that is deposited (with <0.5µm thickness) on top of a periodically corrugated substrate. The grating induces Bragg scattering because of periodic refractive-index modulations, which leads to distributed feedback for the laser. We use active

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layers formed by vacuum co-evaporation of aluminum tris(8-hydroxyquinoline) (Alq₃) doped with 4-dicyanomethylene-2-methyl-6-(p-dimethylaminostyryl)-4H-pyran (DCM) laser dye. The broad emission spectrum of the organic-laser material allows us to tune the laser wavelength between 604 and 724 nm by varying the grating period or layer thickness of the active material.

Figure 2 shows the LOC’s fabrication process. The processing of optical waveguides was based on photodegradation of PMMA through deep-UV (DUV) radiation using a conventional lithography shadow mask. Evanescent-field coupling of DFB-laser light into the PMMA waveguide shows a stable behavior. We enhanced the coupling efficiency by providing maximum overlap of the eigenmodes in both waveguides, which we achieved by end-fire coupling. We adjusted the height of a basin with the DFB grating on the ground to ensure maximum mode overlay of the fields in the laser and PMMA waveguides. Thermal bonding of a lid on top of the basin seals the fluidic trench to form a closed channel and will allow encapsulating the organic semiconductor material.

As an alternative to the lithography process, microfluidic channels may be structured into PMMA bulk material by imprinting technologies. Crossing of a microfluidic channel and a waveguide builds an interaction zone of light and fluid. In a basic experiment—see Figure 3(a)—we showed an integrated waveguide crossing a microfluidic channel used to sense the change of the liquid’s refractive index. We used dip-pen nanolithography in a proof-of-concept experiment exploring the functionalization inside an interaction zone. We coupled laser light into the optical waveguides to excite cyanine-3 (Cy3)-labeled streptavidin in the intersection area: see Figure 3(b).

Achieving an all-organic LOC system requires combining many elements: an organic semiconductor laser-light source, a DUV-induced polymer waveguide, a microfluidic structure, functionalization, and fluorescence excitation. Our experiments show the feasibility of this approach by combining two consecutive elements in this path. Emission from the DFB laser is coupled into a polymer-strip optical waveguide realized by DUV lithography. The waveguide allows optical guiding to a microfluidic channel. Tailored surface functionalization within the microfluidic channel by dip-pen nanolithography enables local excitation of fluorescent markers and thus detection of selected components in biomedically or environmentally relevant fluids. Integrating all functionalities onto one organic LOC is our next goal.

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