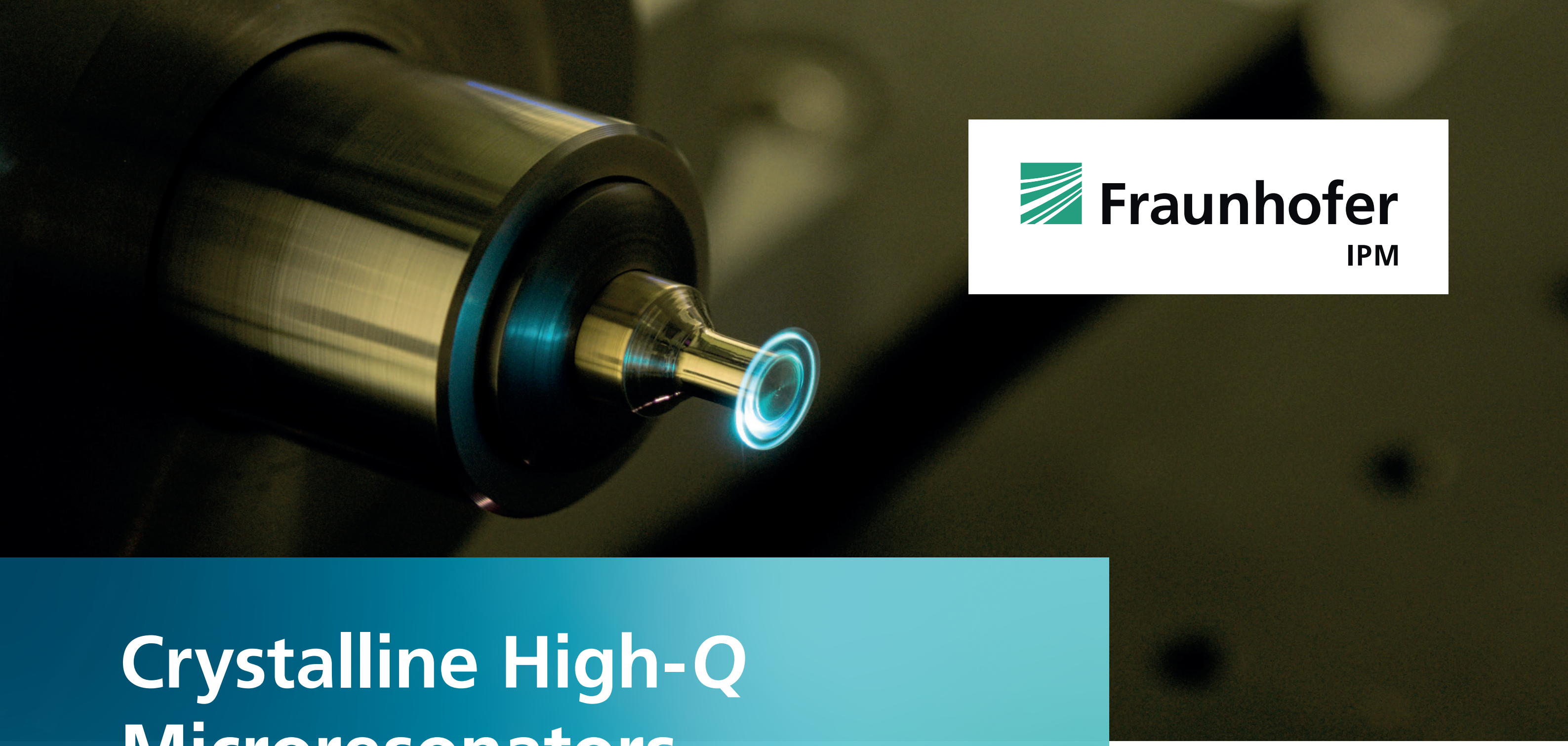


Fraunhofer IPM

Crystalline High-Q Microresonators

A versatile platform for light generation and manipulation

Lithium niobate resonator in the »laser turning lathe«: Laser-processed micro-resonators feature ultra-high Q factors and high efficiencies for nonlinear frequency conversion.

High-*Q* microresonators are key to many microoptic devices like frequency filters, modulators and stimulated or parametric light sources. Fraunhofer IPM and the University of Freiburg's IMTEK Laboratory for Optical Systems have developed a full process chain for both, bulk and on-chip microresonators, to address these applications and turn laboratory systems into real-world devices.

High-quality components for high conversion efficiency

Low-loss micro-optic resonators »trap« light in a (sub)-mm-sized optical loop, forcing it to perform thousands of roundtrips. As a result, linear-optical systems can benefit from a highly frequency selective transmission spectrum, while non-linear optical applications benefit from the enormous light field enhancement inside the microresonator, boosting the non-linear light-matter interaction and giving rise to highly efficient parametric light converters.

In order to cover a maximum of relevant applications, we utilize two resonator concepts: Bulk resonators, fabricated from (sub)-mm-sized crystals, and on-chip resonators made from thin-film material.

Bulk and on-chip resonators

Together, Fraunhofer IPM and IMTEK cover the whole process chain from simulation and design, to fabrication and characterization. The laser-aided **bulk resonator** fabrication process is compatible with almost any optical material. Materials processed include $BaMgF_4$, $LiLuF_4$, MgF_2, CaF, $Li_2B_7O_4$, $LiNbO_3$, $LiTaO_3$, $KTa_xNb_{1-x}O_3$, YVO_4, ZnSe, $AgGaSe_2$, $CdSiP_2$ and GaP, effectively covering a wavelength range from UV to Mid-IR. Typical *Q* factors for bulk resonators are about 10^7 to 10^8, determined by the intrinsic bulk material losses rather than the final surface finishing.

For **on-chip resonators**, lithium niobate-on-insulator (LNOI) technology is the main work horse. We cover the full process chain from LNOI-substrate fabrication and structuring of high-*Q* resonators to optical characterization.

Research cooperation

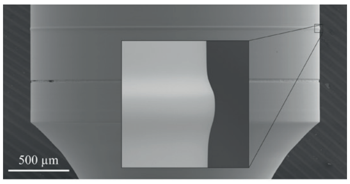
We closely cooperate with University of Freiburg's IMTEK Laboratory for Optical Systems. This gives us access to latest research results – for the benefit of our customers.

IMTEK

Fabrication technologies

Bulk resonators

- Femtosecond laser-aided shaping
- Micrometer-precision shaping for mode-engineering
- Suitable for almost all optical materials



Laser-processed mode-engineered bulk resonator: The inset shows the micro-meter-sized belt, at which light is guided.

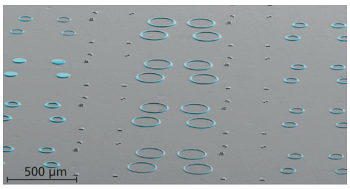
In-house fabrication process for thin-film materials

- Bonding and mechanical thinning instead of ion-slicing
- Ultra-low loss LN-on-insulator (LNOI) substrates
- X-on-insulator upon request

Process steps for thin-film materials

In-house clean room for dry-etched on-chip LNOI-resonators

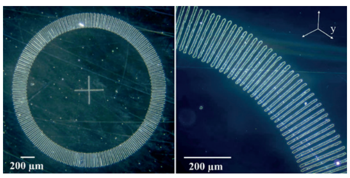
- Hard-masking for deep LN etching
- Wafer-scale sidewall polishing for loss minimization
- Ultra-low loss high-*Q* on-chip microresonators



Various high-Q on-chip LNOI-microresonators

Mask-less lithium niobate poling

- In-house-developed serial poling technique
- Short process time for »one-of-a kind« structures and prototypes
- Homogenous poling quality along any crystallographic axis
- Any 2D poling pattern is possible (e.g. PPLN, fan-out, radial)



Radial poling pattern in congruent melting lithium niobate after domain-selective etching under dark-field illumination

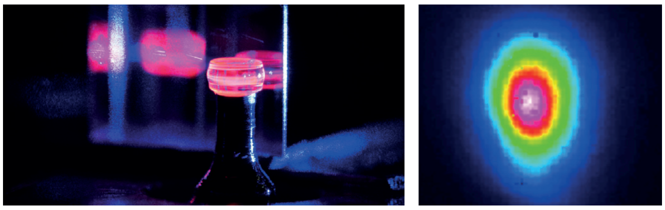
Functionalities

Frequency conversion

- SHG, SFG, DFG, OPO and SPDC
- From below 250 nm to above 8000 nm wavelength
- From single-line to frequency combs
- Ultra-low oscillation threshold and high conversion efficiency

Laser-active resonators

- Single-frequency, tunable and diffraction-limited
- From VIS to NIR
- Combined with intra-cavity frequency conversion



Praseodymium-doped laser-active resonator (left) and a typical emission profile of a microresonator laser (right)

Frequency tuning mechanisms

- Electro-optic, thermal and mechanical tuning

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