

Laser-Assisted Growth of Single Crystals for Optical Isolators

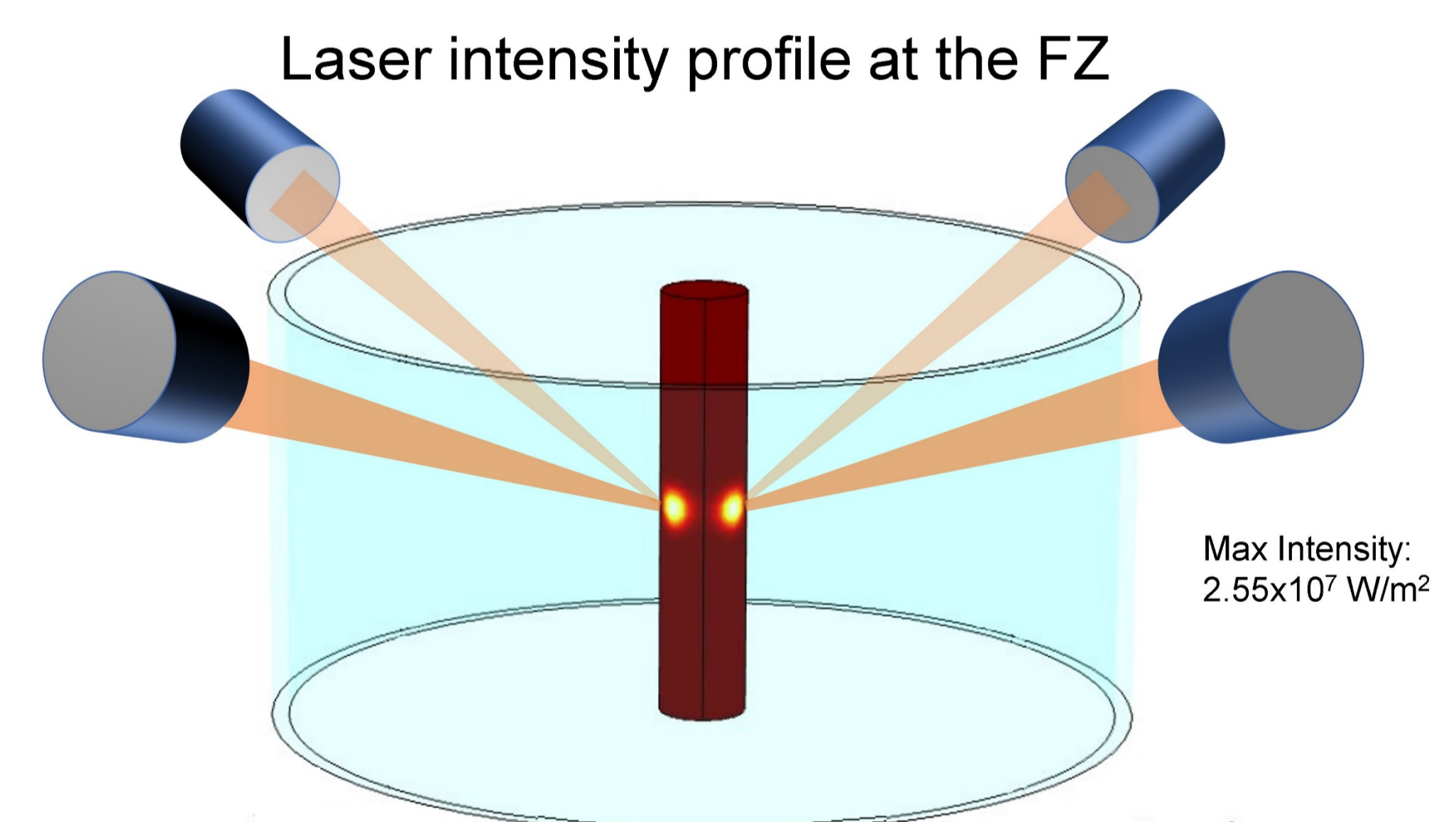
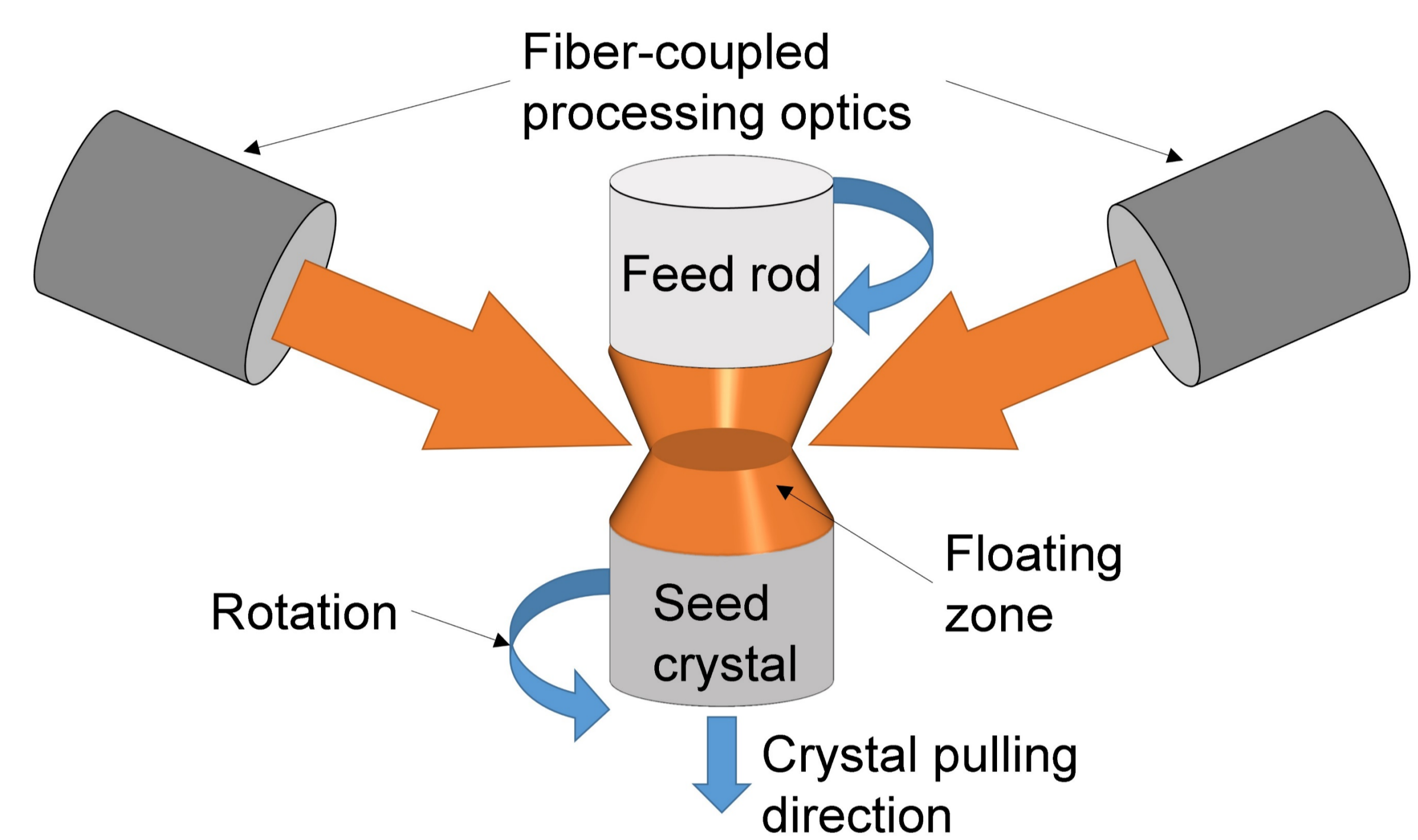
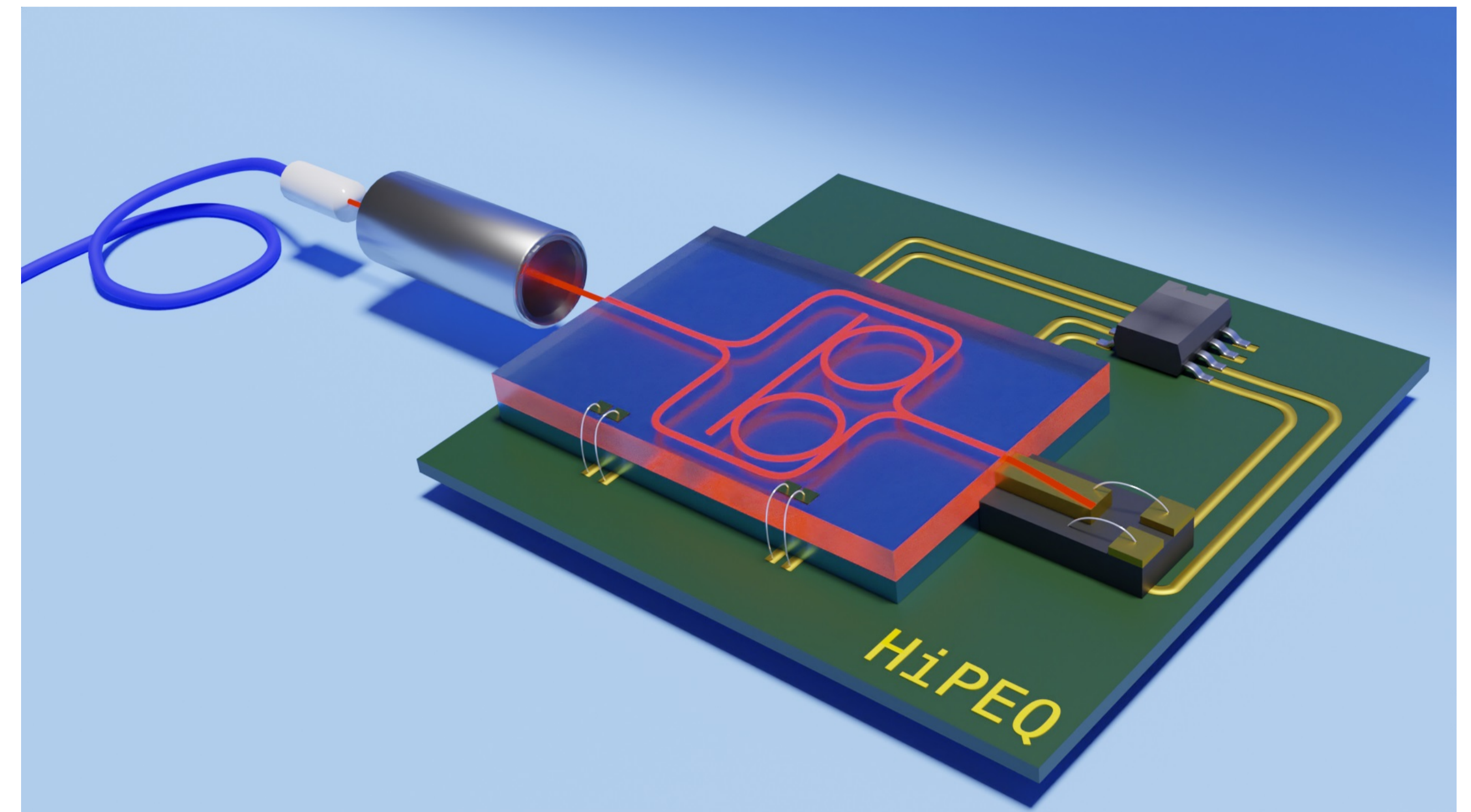
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Due to the high melting temperatures and the complex phase transitions, single crystals for optical isolators are not grown by conventional growth techniques like the Czochralski method. Instead, crucible-free techniques like the optical floating zone method are applied. Using lasers instead of light bulbs allows for a more defined coupling of energy due to the inherent properties of laser radiation. Moreover, customized processing optics generate an intensity distribution that can be adjusted to suit the requirements of a specific crystal growth process. Therefore, the laser-based optical floating zone (LOFZ) method enables the growth of innovative crystal materials, like Tb_2O_3 or CALTO (CaTbAlO_4), that have not been available to a larger group of customers so far.

New materials for optical isolators

- In this project, one of the objectives is the growth of modified terbium oxide single crystals with Verdet constants up to 3 times the value for TGG. Such crystals could pave the way for highly compact isolators with a total volume near 1 cm^3 for laser wavelengths in the blue regime.
- For the growth of pure terbium oxide, the challenges are on one hand the extreme melting point close to 2400°C , and on the other, the occurrence of several structural phase transitions during cool down from the melting point to room temperature. Containing molten terbium oxide around 2400°C is very demanding in terms of crucible material and of thermally insulating materials. Crossing the phase transitions on cooling leads to severe cracks limiting the usable crystal volume.
- We are currently investigating special compositions allowing crystal growth to take place at tractable temperatures and suppressing the phase transitions.
- In addition, novel Faraday crystals of CALTO (CaTbAlO_4) with a somewhat lower but still relatively high Verdet constant and improved transmission in the visible spectral range will also be grown and investigated.



The Laser Optical Floating Zone (LOFZ) Method

- In a LOFZ process, the feed rod and seed crystal are brought in close contact and the contact area is irradiated by laser radiation. Using multi-kW diode lasers in combination with fiber-coupled processing optics, a process-adapted intensity profile is created which enables the melting of the isolator material throughout the floating zone and thereafter the growth of a single crystal.
- Compared to the conventional optical floating zone technique where high-power halogen or argon lamps are used, the LOFZ method allows for a more defined energy coupling due to the directional beam and the adjustable intensity profile. The arising advantages include a better crystal quality, a wider range of accessible crystal materials and a better long-term stability of the process.

Simulation of the heating process during LOFZ

- The resulting temperature profile at the feed rod is the result of the interplay of various physical effects like heat conduction, convective cooling and radiative losses. To understand the impact of these effects, the laser-induced heating of the floating zone is modeled using numerical software. Comparing the results to experimental data, the dominating physical effects can be identified.
- In a second step, the influence of the intensity profile, the wavelength of the laser as well as the emitted power on the temperature distribution at the feed rod will be studied in the framework of thermo-optical simulations.

Isolator crystals grown by the conventional OFZ technique

- One advantage of the OFZ method is the variety of crystal materials that can be grown. Using an existing floating zone furnace, which however is operated by light bulbs instead of lasers, ytterbium aluminium garnet ($\text{Yb}_3\text{Al}_5\text{O}_{12}$) with different doping atoms have been grown. During the growth process, the feed rod and seed crystal are located inside a glass tube which is flown through by a protective gas.
- In the near future, the lamp furnace will be replaced by a laser-based system, which will be used for the further crystal growth experiments within the project.

