Novel laser cavity design by way of transmitting volume Bragg gratings

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Abstract We propose to use transmitting volume Bragg gratings recorded in photo-thermo-refractive glass as high efficient intracavity angular filters in order to achieve high beam quality while using large aperture active medium. The paper describes implementation of novel compact cavity design for solid state lasers, laser diodes, fiber crystal lasers and others.

Keywords—Holographic volume grating, laser cavity

Scaling of the pumping size in gain medium is an efficient way to increase output power, improve heat exchange and suppress nonlinear effects in different types of laser systems. Obviously, the cost of such scaling is degradation of the laser beam quality. Complex, bulk cavities or other special techniques are required in order to obtain lasing with beam quality close to diffraction limit. We propose to use transmitting volume Bragg gratings (VBGs) recorded in photo-thermo-refractive glass (PTR-glass) as high efficient intracavity angular filters in order to achieve high beam quality while using large aperture active medium. In comparison with standard methods of mode selection based on spatial (aperture) mode filtration, VBGs provide highly efficient mode selection in the angular space. Therefore, a very compact and simple laser cavity with extended pumping area could be created based upon such PTR glass holographic elements. The paper describes implementation of this novel laser cavity design for solid state lasers, laser diodes, fiber crystal lasers and others.

While the first VBGs were recorded in PTR-glass long time ago [1], the real attention to these optical components began only when the technology allowed the fabrication of low loss and high efficiency PTR VBGs [2]. These new diffractive optical elements had high tolerance to laser radiation of up to multi kilowatt levels and triggered hundreds of publications in the area of laser applications. Today reflecting VBGs are used significantly more in laser systems in comparison with other elements from the same family. The most well-known application of such volume gratings is the narrowing and wavelength stabilization of the emission of laser diode sources [3] that are used for pumping of solid-state or fiber lasers.

In comparison with reflecting gratings, transmitting VBGs have substantially narrower angular selectivity and wider spectral selectivity. Transmitting VBGs with angular selectivity of less than 50 µrad were demonstrated experimentally and this number is not the limit for our PTR glass technology. Nevertheless, up to now such a unique grating property did not find wide application in laser systems.

We demonstrate experimentally the possibility to use a transmitting VBG for transverse mode selection in different types of lasers with extended pumping region. First, we designed and made a solid state laser based on Nd-doped vanadate crystal and were able to shrink the cavity length by 30 times. The implemented plain cavity had a 10 mm length. The diameter of the pumped area varied from 0.8 to 2 mm (15-94 Fresnel numbers). Without mode selection the measured M² exceeded 5 for pumped area with diameter of 0.8 mm. Modeling showed that the cavity losses for TEM₀₁ mode are 2.5 times higher than the losses for TEM₀₀ mode for wide range of transmitting VBGs with different angular selectivity. The insertion of VGB filters in the laser cavity enabled stable lasing with M²=1.05-1.3 for 0.8-2.0 mm pumping diameters. The slope efficiency was more than 30% for optimal parameters of the VBG filter. This number is very close to the slope efficiency of a stable semispherical cavity with 30 cm length which was used as reference.

Another type of an explored laser was an external cavity strongly multi-mode broad area laser diode with 100 µm stripe. In this case, a compact (~ 3 mm) external cavity was created by off-axis scheme with a transmitting VBG as a transverse mode filter and a reflecting VBG as an output coupler. We obtained lasing with divergence close to the diffraction limit and with efficiency just 15% less than that of a free running LD. High quality emission was obtained for pumping currents which did not exceed 6-7 times the threshold. At higher currents the beam quality degraded quickly due to influences of parasitic reflections from the AR-coated mirror of the internal laser diode cavity. We could substantially expand the mentioned current interval by using the same off-axis scheme with a VBG filter for a 100 µm stripe surface emitting diode laser with a detuned grating output coupler. Additionally, VBG spatial mode selection technique was applied successfully for external cavity fiber crystal lasers and organic VECSEL. Obtained results will be discussed.