Thermal enhancement of optical harmonic generation in a fiber-coupled nematic liquid crystal

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Abstract—The temperature impact on the optical harmonic generation in a fiber-coupled nematic liquid crystal (NLC) pumped by femtosecond laser radiation was explored. A strong thermal enhancement of the third harmonic generation (THG) was revealed. Upon heating to a certain temperature (near the upper limit of the mesophase), the NLC-based converter features a spike of the THG efficiency in excess of 10%. This effect may be attributed to non-critical phase matching. Also appreciable forth harmonic generation in the ultraviolet occurred upon the thermal enhancement of THG.

Keywords—nematic liquid crystal; optical fiber; optical harmonic generation;

Recently a new technique for laser frequency conversion in liquid crystals was proposed and implemented. The conversion was achieved in a microscopic NLC volume deposited on an optical fiber end face: we demonstrated SHG and THG with optical efficiency of \(10^3\) at the room temperature [1]. The advantages of this technique arise from: (1) extremely-high intensity of the fundamental light due to its direct delivery into NLC via a single-mode fiber, (2) capability of effective direct collection of the generated light, not affected by any subsidiary elements like glass cells of usual NLC-based converters [2].

This paper presents a further elaboration of the above technique. We studied temperature dependence of optical harmonic generation capability of a fiber-coupled NLC. It was subjected to a wide-range temperature variation. This treating has revealed sufficient modification of the NLC capability. It has allowed great improvement of THG efficiency and enabled appreciable forth harmonic generation (FGH) as follows.

An NLC drop was deposited on the polished end face of a telecom optical connector with a single-mode fiber. The NLC covered the connector ferule end as a homogeneous layer with a thickness of less than \(100\) nm. A commercial NLC (Merck E7) with the mesophase temperature range -10 to +59 °C was used. The NLC temperature was varied by means of a thermoelectric converter (TEC). Heat transfer between the TEC and the ferule-deposited NLC was achieved through a heat-conducting holder. The temperature was actually controlled at the ferrule holder with an accuracy of \(0.1\) °C. The described fiber-coupled NLC was examined in the temperature interval \(+15...+75°C\). It was pumped by an erbium-based femtosecond fiber laser system identical to the one used in [1]. The central wavelength of the fundamental light was \(156 μm\). Light generated by NLC was investigated using a high-sensitivity wide-range optical spectrum analyzer.

At the room temperature SHG and THG occurred simultaneously (see the spectra in Fig.1). SHG dominated over THG. Conversion efficiency was comparable with [1]. Heating of the NLC did not notably affect SHG. It decayed only in the vicinity of the temperature of nematic-isotropic transition \(T_{NI}\). In the overheated state \(T > T_{NI}\) the SHG recovered due to the light-induced Fréedericksz effect which yielded a local ordering in the isotropic phase. As for the THG, temperature variation revealed a huge intensity peak in a narrow temperature interval centered at \(-52°C\) (Fig. 2). At this point the THG intensity increased dramatically and ranked over the SHG. The estimated THG efficiency reached the level \(10^3\) (comparable with the quantum limit). Such effect may be attributed to noncritical phase matching or self-phase matching. In both cases THG can be thermally adjusted [2].

An important side effect of the thermally-enhanced THG is the evident appearance of FGH (Fig.1). It arises mainly from mixing the 3-rd harmonic with the fundamental light.

Fig. 1. Spectra of optical harmonics: black curves – generation at room temperature: grey – at the temperature of THG enhancement (52.3 °C).

Fig. 2. Temperature dependence of the THG spectral intensity.

Thus, the temperature adjustment of the NLC-based fiber-coupled laser frequency convertor ensures high-efficiency THG and enables coherent ultraviolet radiation through FGH.
