Towards spontaneous parametric down-conversion at low temperatures

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Abstract. The possibility of observing spontaneous parametric down-conversion in doped nonlinear crystals at low temperatures, which would be useful for combining heralded single-photon sources and quantum memories, is studied theoretically. The ordinary refractive index of a lithium niobate crystal doped with magnesium oxide $LiNbO_3$:MgO is measured at liquid nitrogen and helium temperatures. On the basis of the experimental data, the coefficients of the Sellmeier equation are determined for the temperatures from 5 to 300 K. In addition, a poling period of the nonlinear crystal has been calculated for observing type-0 spontaneous parametric down-conversion (ooo-synchronism) at the liquid helium temperature under pumping at the wavelength of λ_p = 532 nm and emission of the signal field at the wavelength of λ_s = 794 nm, which corresponds to the resonant absorption line of Tm^{3+} doped ions.

1 Introduction

Spontaneous parametric down-conversion (SPDC) is the most common way of generating non-classical states of the electromagnetic field, in particular single-photon or two-photon states [1, 2]. When such states are used in the systems of long-distance quantum communications or quantum computing, it may be useful to have the possibility to store them in a quantum memory device immediately after their generation. In this case, the optimal solution might be the combination of the SPDC-based photon source and quantum memory in a single system utilizing a doped nonlinear crystal as an information carrier. Since solid-state quantum memories typically work at liquid-helium temperature, it is necessary that single-photon or two-photon sources do the same. However, to our knowledge, no one has experimentally studied SPDC under such conditions. Furthermore, even temperature dependence of refractive indices of nonlinear crystals that could be used for combining single-photon sources and quantum memories has not been investigated at low temperatures. A promising example is the lithium niobate crystal doped with trivalent thulium ions [3]. In the pre-sent work, we study the possibility of observing SPDC at low temperatures in such nonlinear crystals.

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2 Basic results

For the present theoretical and experimental study, we have chosen lithium niobate crystal doped with magnesium oxide (5%) $LiNbO_3$:MgO produced by “Labfer”. The dependence of the ordinary refractive index on the wavelength has been measured at different temperatures (see Table 1 and Figure 1).

Table 1. The measured deviation of ordinary refractive index $\Delta n = n_T - n_{298\,K}$ from its room temperature value for the lithium niobate crystal doped with magnesium oxide $LiNbO_3$:MgO (5%) for some temperatures and wavelengths.

	λ = 0.53775 μm	λ = 0.812 μm	λ = 1.075 μm	λ = 1.55 μm
T = 4.3 K	-0.0025	-0.0012	-0.006	-0.006
T = 77.4 K	-0.0034	-0.0011	-0.006	-0.006
T = 298 K	0	0	0	0

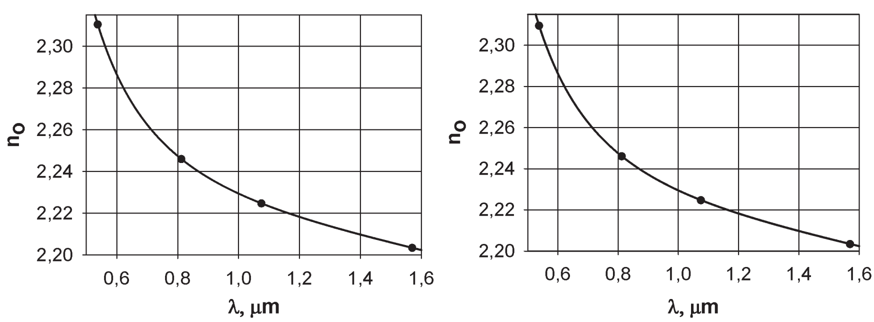

Fig. 1. The dependence of the ordinary refractive index on the wavelength at liquid helium (left) and liquid nitrogen (right) temperature. The circles represent experimental data, while the solid line is the approximation using modified Sellmeier equations.

On the basis of the experimental data, we study the possibility of observing type-0 SPDC at the liquid helium temperature under pumping at the wavelength of λ_p = 532 nm and emission of the signal field at the wavelength of λ_s = 794 nm, which corresponds to the resonant absorption line of Tm^{3+} doped ions. Numerics show that in this case the lithium niobate crystal should have the poling period about Λ = 6.63 μm. Such a regime of SPDC would be useful for combining a heralded single-photon source and quantum memory device in a single crystal, since the wavelength of the signal photons corresponds to the resonant absorption line of Tm^{3+} doped ions. The preliminary experimental work has been carried out [4] which demonstrates the possibility of SPDC in this crystal at temperatures below 0˚C.

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