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INTRACAVITY SECOND HARMONIC GENERATION OF 0.532 μm IN BULK PERIODICALLY POLED LITHIUM NIOBATE

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Abstract: CW quasi-phase-matched intracavity frequency doubling of 1.064 μm Nd:YAG laser is reported for the first time. The 5 mm long and 0.2 mm thick crystal of periodically poled $LiNbO_3$ was Brewster angle cut. When located intracavity, it presented an effective nonlinear coefficient d_{33} of 4.5 pm/V and an estimated loss per pass less than 10 %. The observed temperature bandwidth of approximately 5 K compares favourably with the theoretical value.

Introduction: Intracavity second harmonic generation (ISHG) of Nd-doped lasers has always been a very attractive method for producing coherent green light [1]. In order to achieve efficient operation it is necessary to use bulk materials with high nonlinearities, good optical quality, low loss and - most important - the ability to satisfy the non-critical phase-matching condition. In principle, periodically poled lithium niobate (PPLN) satisfies all these requirements.

Highly efficient quasi-phase-matched SHG of blue light has been achieved both in bulk [2,3] and waveguide devices of PPLN [4]. Compensation of the phase mis-match by a periodic domain reversal allows access to the largest nonlinear coefficient $d_{eff}=2/\pi*d_{33}=20.9$ pm/V and avoids walk-off problems since fundamental and generated waves are both *z*-polarized. Jundt et al [5] demonstrated efficient extracavity SHG of the Nd:YAG 1.064 μm line in a 1.4 mm long AR coated crystal of PPLN by resonating the fundamental in an external cavity. Frequency locking of this cavity to the laser cavity was therefore necessary.

We report preliminary results which, for the first time to our knowledge, demonstrate the use of a bulk PPLN crystal for ISHG of a Nd:YAG laser.

Fabrication and characterization of the PPLN crystal: A 0.2 mm thick sample was periodically inverted, with a pitch of 6.8 μm, using high-voltage pulses applied via periodic liquid electrodes [6]. The sample was subjected to 3 pulses with a total duration of 13 ms. The average poling current during the pulses was 0.65 mA. After poling, a large amount of strain was evident when the sample was observed between crossed polarizers. This strain was nearly completely removed by low-temperature annealing (the oven was ramped up to 250°C at a rate of 130°C/hour and then switched off and allowed to cool down to room temperature). The end-faces were polished at the Brewster angle of 65°. Cerium oxide was used, since Syton was found to polish positive and negative domains at different rates.

Before placing the sample in the Nd:YAG laser cavity, some single-pass optical measurements were carried out. Using a temperature-controlled holder, the sample was heated to around 35°C in order to achieve phase-matching for frequency doubling of 1064 nm radiation. The nonlinear coefficient was estimated to be 5 pm/V, about four times smaller than the theoretical value. We attribute this disparity to non-optimised geometry in the PPLN grating.

Fig.1 shows the SH output as a function of temperature. The bandwidth of the phase-matching curve is close to the theoretical prediction of about 5°K. This means that the full length of the sample contributes to the SHG. The SH power was proportional to the square of the fundamental power up to our experimental limit of 200 mW, indicating the absence of photorefractive damage.

Description and performance of the Nd:YAG cavity: The cavity, shown in Fig.2, was astigmatically compensated. In its design and alignment, particular attention was paid to reducing the diffractive losses connected with the small thickness of the PPLN. The fundamental mode spot-size in the Nd:YAG rod was 125 μm, while in the PPLN crystal the spot was estimated to be 18 μm in the tangential and 43 μm in the sagittal planes. In this preliminary experiment, the 7 mm long Nd:YAG rod was end-pumped by a Ti:Sapphire laser. The maximum infrared power leaving the cavity, through the output coupling mirror (1.5% transmission), was 6.8 mW, while the threshold pump power was 90 mW - six times higher than the corresponding value without the PPLN crystal in the cavity. The total loss per pass in the crystal could then be estimated at less than 10%, mainly due, we believe, to the non-optimum quality of the surfaces and the clipping of the laser beam.

The maximum SH power extracted from the cavity was 400 μW when the intracavity fundamental power was approximately 450 mW and the pump power 480 mW. From these powers the effective value of the nonlinear coefficient was estimated to be 4.5 pm/V, slightly less than the one estimated in the single-pass extracavity experiment.

Fig.3 shows the square-law dependence of the generated SH power on the intracavity fundamental power, indicating that the effects of the photorefractive damage are negligible. This result was also confirmed by the reasonably good beam quality of both infrared and green light.

Discussion and conclusions: Intracavity second harmonic generation in a bulk PPLN crystal, prepared by electric field poling, has been demonstrated for the first time. The performance of the crystal, in terms of nonlinear coefficient, loss, optical quality and interaction length, are promising for future developments in high efficiency second-order nonlinear applications. Considerable improvements can be gained by increasing the thickness of the sample to 500 μm and by optimizing the surface quality, the structure of the grating and the design of the resonator. These results are important indicators for further exploitation of this material in optical parametric oscillators [7], non-linear mirror geometries for ultrashort pulse generation [8] and efficient intracavity doubling at any other wavelength within the transmission range of lithium niobate (400 nm to 4 μm), especially where there are no materials available to provide non-critical birefringent phase-matching (e.g. SH conversion of 946 nm to blue light).

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Figure Captions

1. Second-harmonic power as function of crystal temperature. The continuous line is the computation for a perfect crystal of the same length.

2. Resonator for ISHG of Nd:YAG.

3. Second harmonic power as a function of the intracavity fundamental power.

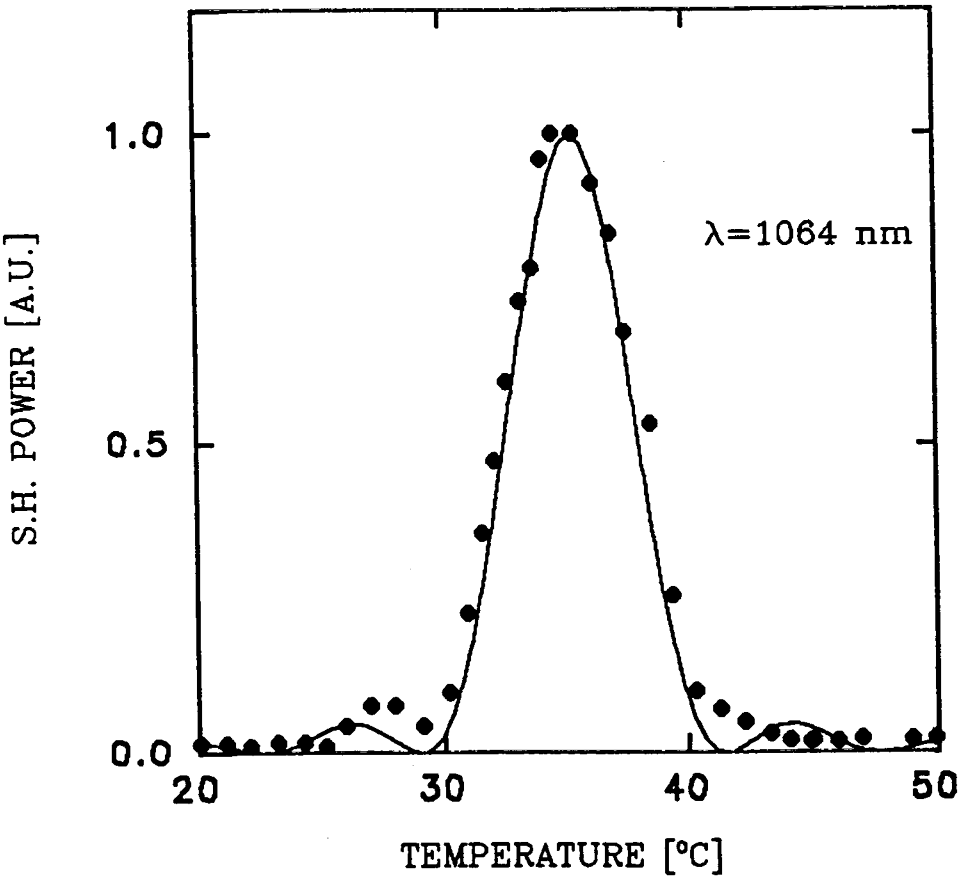

FIG.1

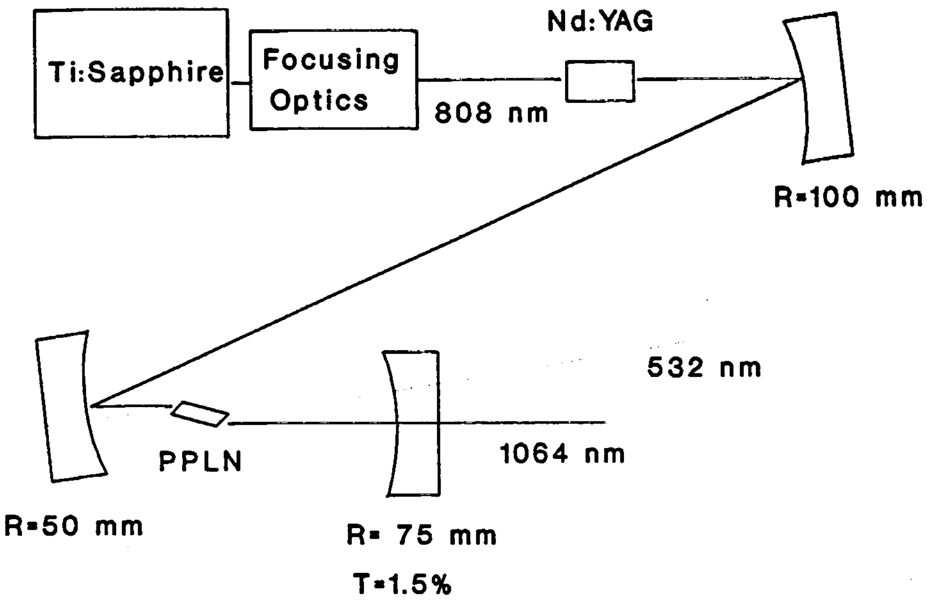
Ti:Sapphire
Focusing Optics
808 nm
Nd:YAG
R=100 mm
532 nm
1064 nm
PPLN
R=50 mm
R= 75 mm
T=1.5%

FIG.2

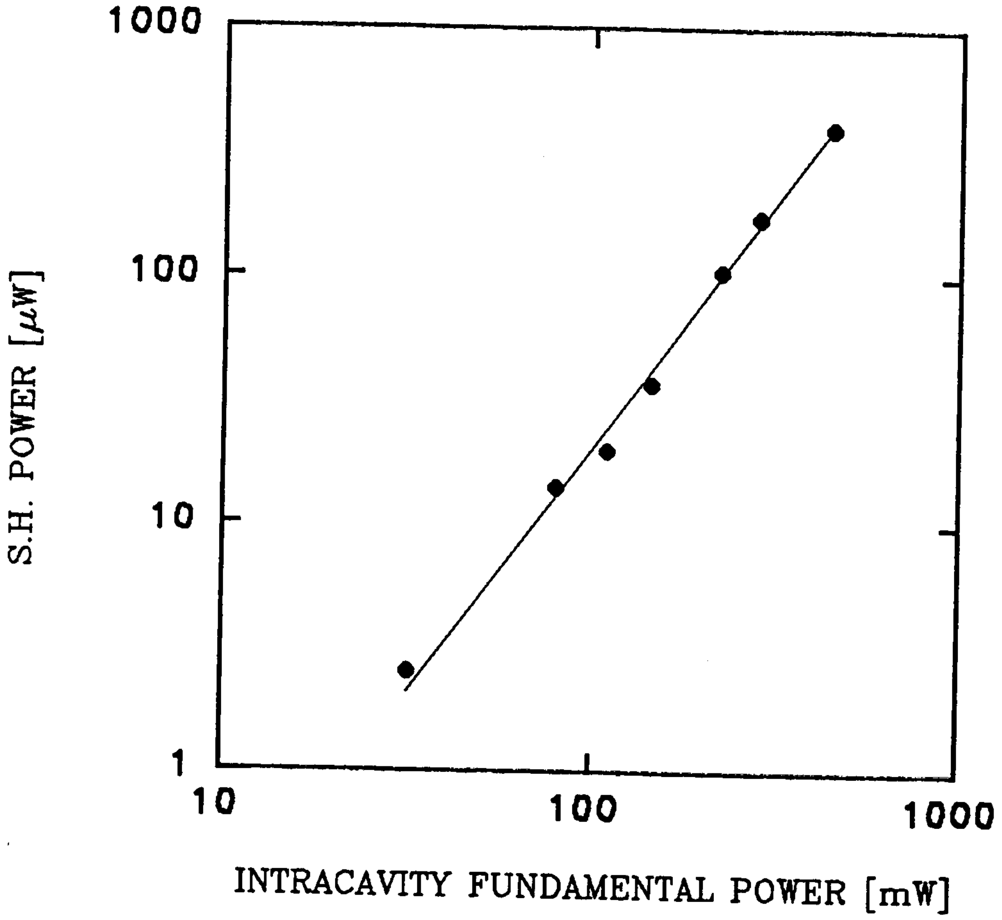
1000
100
10
1
10
100
1000
S.H. POWER [μW]
INTRACAVITY FUNDAMENTAL POWER [mW]

FIG.3