

**Generation of Coherent Radiation Continuously Tunable in
515-650-nm Range by Efficient Second Harmonic Conversion
of LiF:F₂⁻ Laser Radiation**

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Outline

1. Motivation
2. Optical properties of LiF:F_2^- Laser Crystals:
3. LiF:F_2^- Laser Operation:
 - Pump Lasers
 - Experimental Set-Up
 - Non-selective resonator
 - Tuning Range
4. SHG of the LiF:F_2^- Laser in a NCPM, Temperature-Tuned LBO Crystal
5. Conclusions

Motivation

- Efficient frequency doubling of LiF:F_2^- laser with 1030-1300-nm tuning range to generate 515-650-nm radiation.

Previous results – LiF:F₂⁻

□ Maximum output efficiency (selective resonator):

~ 40% - **Nd:YLF excitation**

S.B. Mirov and T.T. Basiev, “*Progress in Color Center Lasers*”
IEEE J. of Special Topics in Quantum Electronics, **1**, 22-30 (1995)

~ 40% - **Nd:YAG excitation (60% in non-selective cavity)**

V. V. Ter-Mikirtychev, “*Efficient room-temperature tunable color center lasers and passive Q-switches based on LiF:F₂⁻ crystals*”,
Opt. Commun. **119**, 109-112 (1995)

□ Maximum output (non-selective resonator):

~ 100 J (500 J 1.06 Nd:glass laser pump)

T.T. Basiev, B.V. Ershov, S.B. Kravtsov, S.B. Mirov, V.A. Spiridonov,
V.B.Fedorov,
“*Lithium fluoride color center laser with an output energy of 100 J*”,
Sov. J. Quantum Electron., **15 (6)** , 745-746 (1985)

□ Maximum SHG efficiency of LiF:F₂⁻:

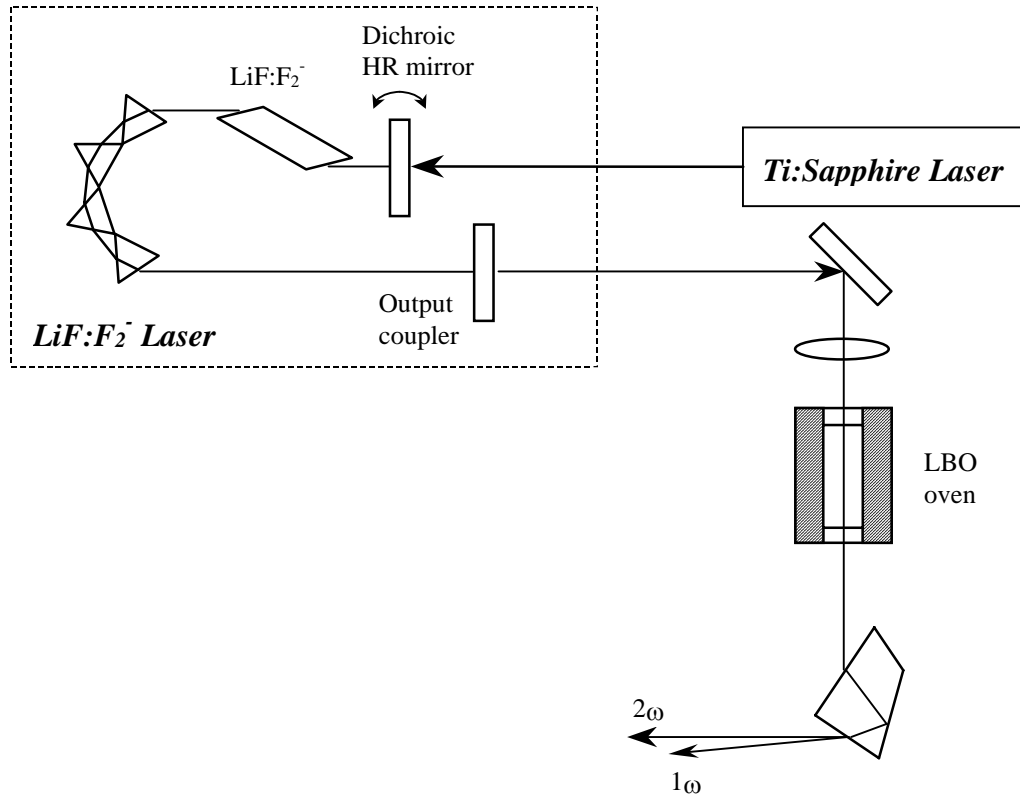
~ 30 % (2-cm long LiNbO₃)

T.T. Basiev, V.A. Konyushkin, S.B. Mirov, V.V. Ter-Mikirtychev,
V.V.Fedorov,
“*Lasing Characteristics of Room Temperature Tunable Lasers based on LiF Crystals Utilizing F₂⁺ and F₂⁻ Color Centers*”
Russian J. Optics and Spectroscopy, **74**, 1217-1221 (1993)

Laser Properties of LiF:F₂⁻ Crystals

Material	LiF:F ₂ ⁻	Ti:sapphire
Luminescence maximum, nm	1140	760
Luminescence halfwidth, nm	160	175
Luminescence lifetime, ns 300 K 77 K	55 85	3150
Emission cross-section, cm ²	6.97×10^{-17}	2.7×10^{-19}
Laser threshold, J/cm ²	$\leq 1 \times 10^{-3}$	~ 1
Quantum efficiency	0.65	0.80
Damage threshold, J/cm ²	~ 10	~ 10
Coefficient of heat conductivity, W/m·K	14.2	35.0

Experimental Set-Up



□ *LiF:F₂⁻ Active Element:*

- parallel Brewster-cut faces,
- 25 mm long
- clear aperture 8x15 mm.

□ *Resonator and Mirrors:*

- flat-flat resonator (length ~ 40 cm)
- input dichroic mirror: $T \geq 91\%$ at 945 nm
 $R \geq 99\%$ at 1050-1300 nm.
- output couplers: $R \sim 20\%$ - 1000-1300 nm

Pump Lasers

□ **General case:**

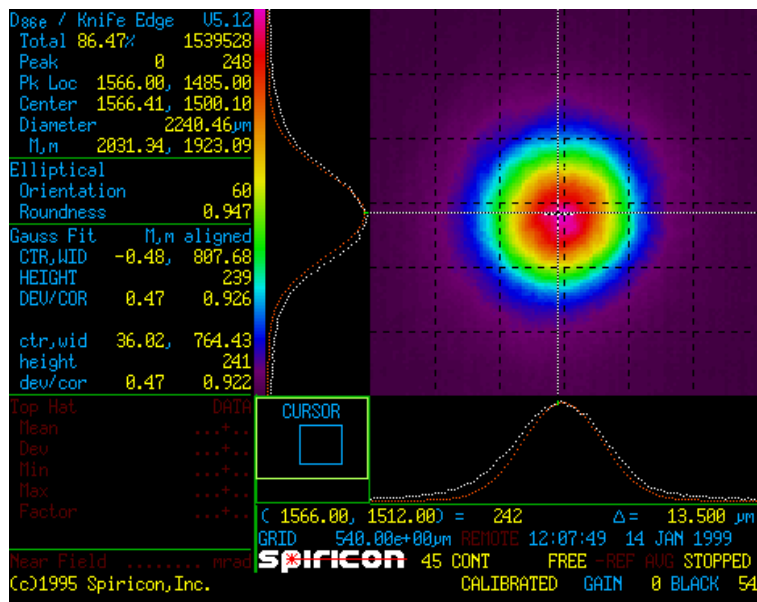
LiF:F₂⁻ can be pumped by the radiation of any laser or laser diode emitting in the 900-1070-nm range e.g.:

Nd:YLF 1047 or 1053 nm
 Nd:YAG 1064 nm

□ **This work:**

Pumping laser	Wavelength, nm	Energy per pulse, mJ	Pulse width, ns	Repetition rate, Hz
Ti:sapphire laser	945	up to 100	~ 40	10

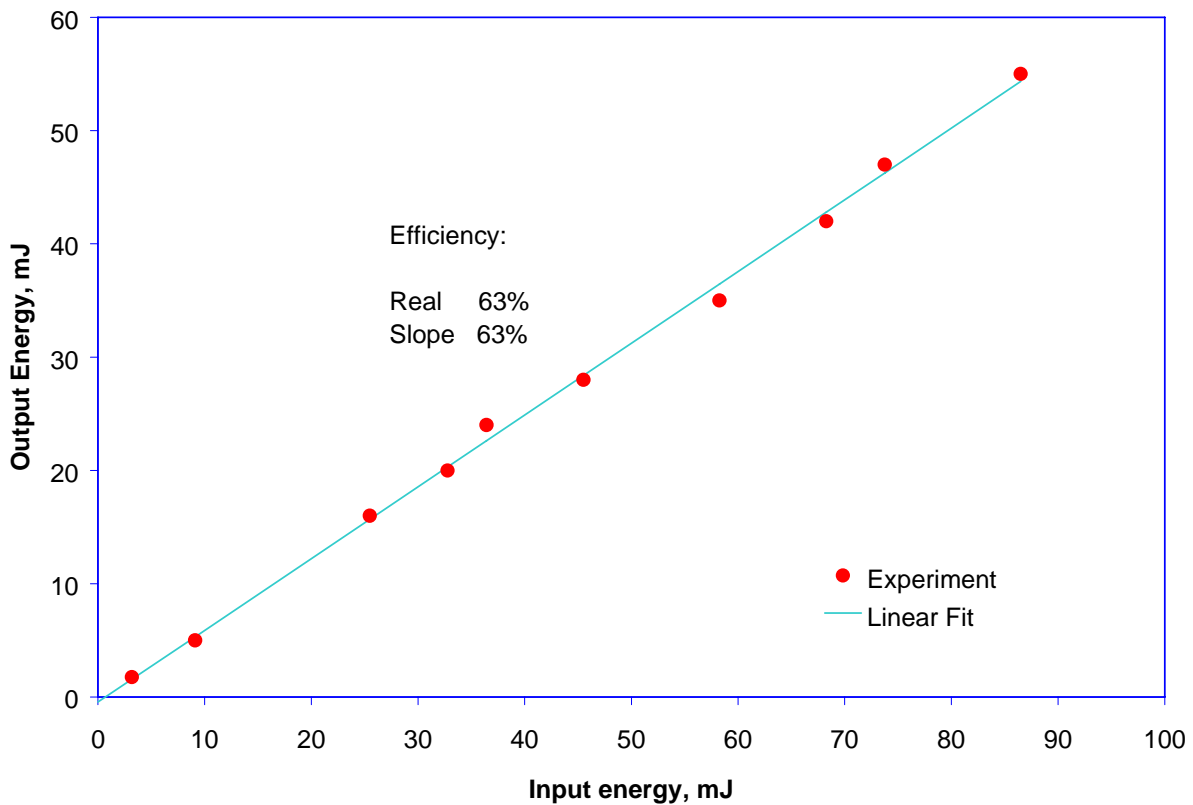
- Ti:sapphire laser - pumped by frequency-doubled flashlamp-pumped Nd:YLF laser (527 nm, up to 500 mJ, 10 ns)



b) 945 nm, 110 mJ

Figure Beam profile for Ti:sapphire laser operated at 945 nm

LiF:F₂⁻ Laser Operation (Non-selective resonator)



□ Flat/flat non-selective resonator:

Dichroic HR mirror: $R > 99\%$ at $\sim 1050\text{-}1300$ nm

$T \geq 91\%$ at 945 nm

Output coupler: $R \sim 20\%$ at $1000\text{-}1300$ nm

Length: 15 cm

Tuning Range of LiF:F₂⁻ Laser

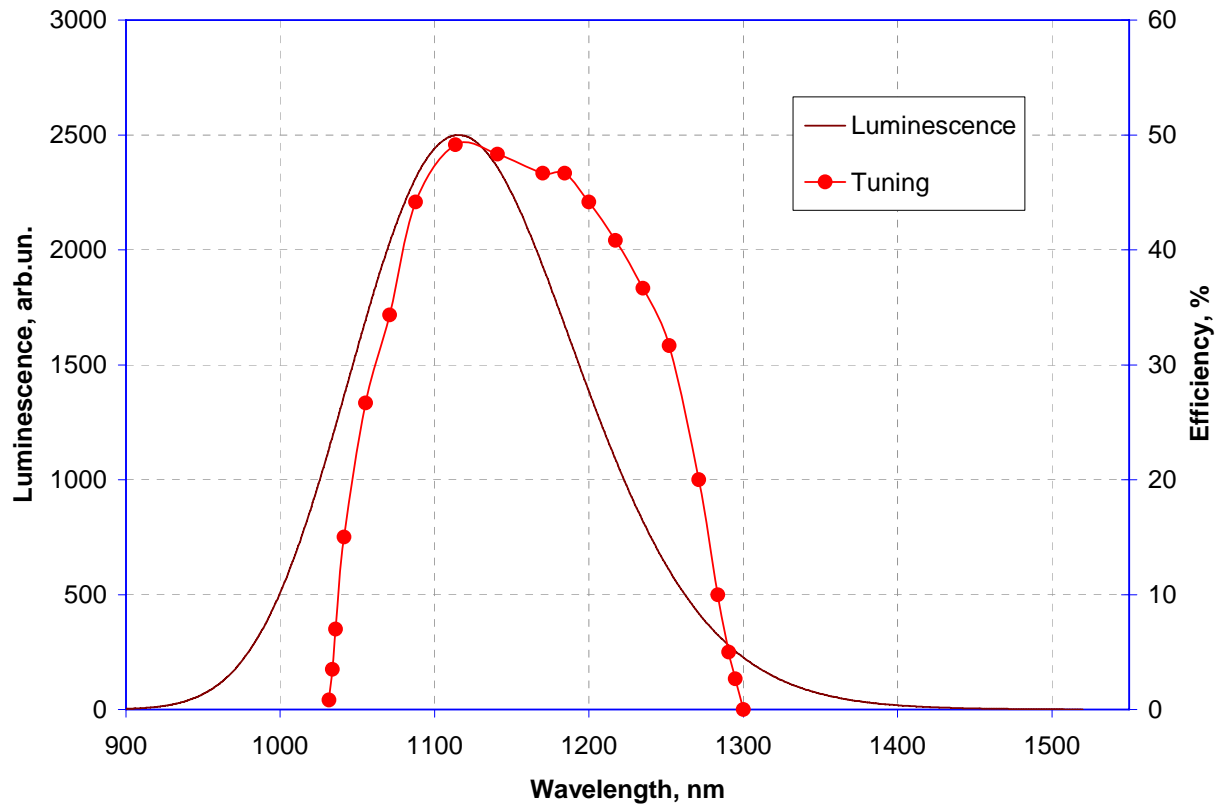


Figure Luminescence and laser tuning curves of F₂⁻ color centers in LiF laser crystal at 300 K.

Discussion – LiF:F₂⁻ laser:

- ❑ Room-temperature photo- and thermostable operation
- ❑ Record real efficiency:
 - ~ 63% with non-selective resonator
 - up to ~ 50% with selective resonator
- ❑ Record levels of output energy per pulse up to ~40 mJ (with “small” pump lasers)
- ❑ Wide 1030 - 1300 nm tuning range (when pumped near the absorption peak of F₂⁻ color centers in the 900-960-nm range).

Comparison of Critical and Non-Critical Phase Matching for SHG in LBO Crystal

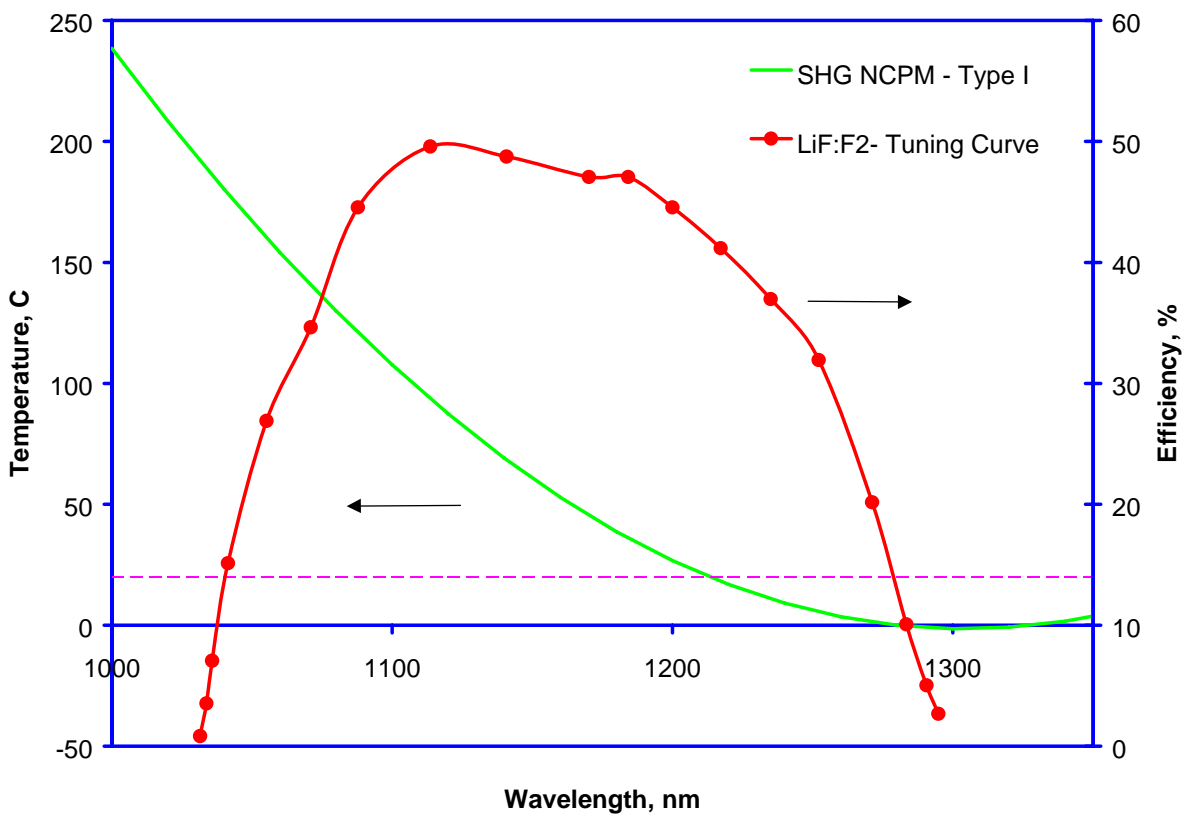
SHG - Critical Phase-Matching at 20 °C

λ , nm	θ , deg.	ϕ , deg.	Walk-off, mrad	$\Delta\theta$, mrad	$\Delta\phi$, mrad	ΔT , °C	$\Delta\lambda$, nm
1100	90.0	9.4	5.7(ϕ)	48.2	5.3	6.4	4.9
1200	90.0	2.5	1.6(ϕ)	50.6	22.4	6.8	12.2
1300	86.4	0.0	3.2(θ)	11.2	64.1	7.4	79.4

SHG – NCPM (zero walk-off)

λ , nm	θ , deg.	ϕ , deg.	T, °C	$\Delta\theta$, mrad	$\Delta\phi$, mrad	ΔT , °C	$\Delta\lambda$, nm
1100	90.0	0.0	107.6	48.0	59.6	5.3	4.9
1200	90.0	0.0	26.7	50.6	61.4	6.7	12.2
1300	90.0	0.0	-1.4	52.8	63.7	7.7	79.6

Temperature of NCPM for SHG in LBO Crystals (Type I) and Tuning Curve for LiF:F₂⁻ laser



Calculations based on the data from:

K. Kato, IEEE J. of Quantum Electron. **30**, 2950 (1994)

SHG of the LiF:F₂⁻ Laser in a NCPM, Temperature-Tuned LBO Crystal

Discussion:

- ❑ By changing the temperature of the LBO crystal, it is possible to maintain non-critical phase-matching conditions for the whole tuning range of LiF:F₂⁻ laser
- ❑ advantages of SHG in NCPM LBO material:
 - zero walk-off,
 - wide spectral acceptance bandwidth,
 - wide angular acceptance bandwidth and therefore the possibility for tight focusing of the fundamental beam.
 - extremely high optical damage threshold (>15 GW/cm² for ns pulses) -> nonlinear conversion of high-energy lasers

Experiment:

- ❑ LBO crystal: 17 mm long, uncoated
- ❑ Oven temperature: RT - 200 C
- ❑ Focusing lens: 50 cm
- ❑ Max input energy: 35 mJ
- ❑ Max output energy
 - Total 32 mJ
 - SHG 15 mJ
- ❑ Conversion efficiency: ~ 45-50% (1070-1220 nm range)

Conclusions

1. Development of an efficient tunable, room temperature LiF:F₂⁺ laser:

- Combines the advantages of a dye laser: *high quantum efficiency, large emission cross section, and wide tuning range*, with
- the advantages of solid state laser media: *crystalline host, high thermal conductivity, easy handling and high optical damage threshold*.
- Possibility for *easy scaling* of the LiF:F₂⁺ laser (almost unreachable for dye lasers and OPOs). Crystal sizes as large as Ø 400x200 mm can be achieved for LiF.
- Good alternative for OPOs and pulsed tunable lasers based on impurity-doped crystals in 1000-1300-nm range: feature *high gain and low threshold*, and are relatively *insensitive to the quality of the cavity optical elements as well as the spatial, angular and spectral characteristics of the pump source*. Free of such difficulties, common to OPOs, as spectral line stability and high threshold of a narrow-linewidth generation.

2. Frequency doubling:

- We demonstrated, to the best of our knowledge, the highest conversion efficiency ~ 50 % for the frequency doubling of the LiF:F₂⁺ laser. The LiF:F₂⁺ - LBO combination can be used as an efficient all-solid-state source of coherent radiation in 515-650 nm range.