# Ultraviolet Laser Source Based on Nonlinearly Frequency–Converted Copper and Copper Bromide Vapor Laser Systems

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## INTRODUCTION

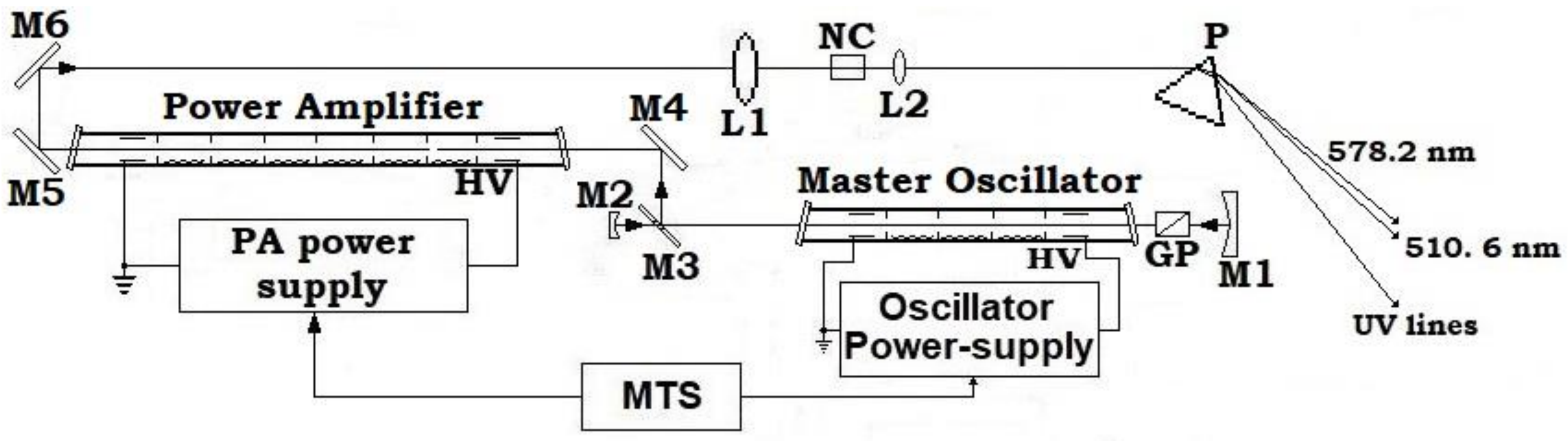
**Precise micromachining with laser ablation requires ultraviolet or deep ultraviolet (UV and DUV) laser radiation, since the processed area size after focusing linearly depends on the laser radiation wavelength. In addition to the high resolution, the UV and DUV laser radiations have sufficiently high enough photon energy to induce some phenomena in different materials, such as material and its surface modification, fluorescence, image recording, etc. Nonlinear frequency conversion is a well-known method for oscillating in the UV and DUV spectral ranges. Several UV and DUV laser sources have been well developed and investigated, such as frequency-quadrupled and frequency-tripled Nd:YAG and Nd:YLF lasers, frequency-doubled argon ion lasers, and frequency-doubled dye lasers.**

**UV laser sources based on nonlinear frequency conversion of copper vapor laser (CVL) radiation at high pulse recurrence frequency (5-20 kHz) is quite competitive alternative. CVLs operate at the atomic copper 510.6- and 578.2-nm lines. UV radiation at 255.3 nm, 289.1 nm and 271.2 nm has been generated in various nonlinear crystals, namely Potassium Dihydrogen Phosphate (KDP), *β*-barium borate (BBO) and cesium lithium borate (CLBO) by frequency doubling the 510.6-nm and 578.2-nm output and sum-frequency generation of the two laser lines. Applying spherical optics for the laser beam focusing in a β-barium borate (BBO) nonlinear crystal, the maximal DUV laser power at the 255.3-nm laser line has been 450 mW through frequency doubling the 510.6-nm output (T. S. Petrov et al). Utilizing cylindrical optics instead of spherical ones to reduce the hazard of nonlinear crystal damage at high average pump laser power (M. J. Withford et al; D. J. W. Brown et al), the DUV laser power has been consecutively increased from 1.3 W (M. J. Withford et al) to 3 W via nonlinear BBO crystals (D. J. W. Brown et al) and up to 15 W with a nonlinear crystal made of CLBO (D. J. W. Brown et al).**

## AIM

**To develop and study a reliable laser source, which operates at the DUV laser lines of 255.3 nm, 289.1 nm and 271.2 nm by frequency conversion of MO–PA Cu (CuBr) vapor system output in BBO and KDPnonlinear crystals using spherical optics.**

## EXPERIMENTAL SETUP




**(a)**

**Fig. 1. Schematic diagram of studied MO–PA CuBr vapor (a) and MO Cu vapor – DPA CuBr vapor (b) systems.**

**(b)**

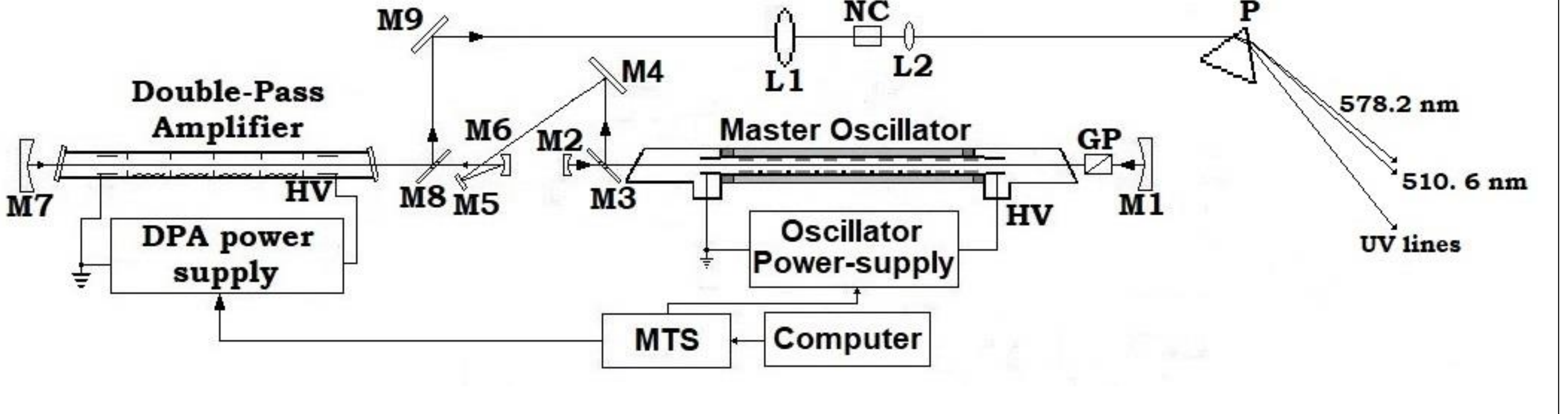



**Table 1.** Parameters of optical elements.

| MO | Optics | M1 | M2 | M3 | | M4 | M5 | M6 | M7 | M8 | | M9 | L1 | L2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | Focal length (cm) | 115 | 2.5 | ∞ | 0.5-mm orifice | ∞ | ∞ | ∞ | – | – | | – | 100 | 15 |
| (b) | Focal length (cm) | 115 | 5.0 | ∞ | 0.5-mm orifice | ∞ | ∞ | 50 | 250 | ∞ | 0.5-mm orifice | ∞ | 100 | 15 |

## EXPERIMENTAL RESULTS

**Table 2.** Summary of our frequency conversion results with maximal UV average laser power and maximal conversion efficiency: $\lambda_p$ – pump laser wavelength; $\lambda_G$ – nonlinearly conversed wavelength; ***D*** – laser beam diameter; ***f*** – focusing distance; ***f / D*** – focusing number; $P_{out}^{Pump}$ – average pump power at 510.6 nm, 578.2 nm and total average pump power at multiline laser oscillation; $P_{out}^{UV}$ – ultraviolet average power; $\eta$ – conversion efficiency.

| Master Oscillator | | | Power Amplifier | | | Important Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_a$ (mm) | $l_a$ (cm) | $V_a$ (cm$^3$) | $d_a$ (mm) | $l_a$ (cm) | $V_a$ (cm$^3$) | Nonlinear crystal | $\lambda_P$ (nm) | $\lambda_G$ (nm) | $D$ (mm) | $f$ (cm) | $f/D$ | $P_{out}^{Pump}$ (W) | $P_{out}^{UV}$ (mW) | $\eta$ (%) |
| 20 | 50 | 157.1 | 20 | 50 | 157.1 | 15-mm BBO | 510.6 | 255.3 | 18 | 75 | 42 | 7.20 | 1610 | 22.36 |
| 20 | 50 | 157.1 | 20 | 50 | 157.1 | 15-mm BBO | 510.6 | 255.3 | 18 | 100 | 56 | 10.00 | 1255 | 12.55 |
| | | | | | | | | | | | | 1.00 | 152 | 15.20 |
| 20 | 50 | 157.1 | | | | 15-mm BBO | 510.6 | 255.3 | 8 / 18 | 75 | 94 / 42 | 4.80 | 1369 | 28.52 |
| 20 | 50 | 157.1 | | | | 15-mm BBO | 510.6 | 255.3 | 6 / 18 | 75 | 125 / 42 | 3.00 | 916 | 30.53 |
| 20 | 50 | 157.1 | 11 | 63 | 59.9 | 15-mm BBO | 510.6 | 255.3 | 10 | 40 | 40 | 4.55 | 1060 | 23.30 |
| | | | | | | | | | | | | 0.23 | 63 | 27.39 |
| 20 | 50 | 157.1 | 11 | 63 | 59.9 | 15-mm BBO | 510.6 | 255.3 | 4 / 10 | 40 | 100 / 40 | 1.67 | 515 | 30.84 |
| | | | | | | | | | | | | 0.52 | 191 | 36.64 |
| 20 | 50 | 157.1 | 15 | 63 | 111.3 | 15-mm BBO | 510.6 | 255.3 | 14 | 100 | 71 | 8.00 | 1060 | 13.25 |
| | | | | | | | | | | | | 5.50 | 766 | 13.93 |
| 3 | 30 | 2.1 | 15 | 63 | 111.3 | 15-mm BBO | 510.6 | 255.3 | 14 | 40 | 29 | 3.41 | 985 | 28.89 |
| | | | | | | | | | | | | 3.35 | 979 | 29.22 |
| 3 | 30 | 2.1 | 15 | 63 | 111.3 | 15-mm BBO | 510.6 | 255.3 | 14 | 100 | 71 | 5.40 | 615 | 11.39 |
| | | | | | | | | | | | | 5.00 | 586 | 11.72 |
| 3 | 30 | 2.1 | 15 | 63 | 111.3 | 15-mm BBO | 510.6 | 255.3 | 8 | 20 | 25 | 1.47 | 353 | 24.01 |
| 3 | 30 | 2.1 | 15 | 63 | 111.3 | 15-mm BBO | 510.6 | 255.3 | 6 | 20 | 33 | 1.15 | 310 | 26.96 |
| 3 | 30 | 2.1 | 15 | 63 | 111.3 | 5-mm BBO | 510.6 | 255.3 | 6 | 20 | 33 | 0.81 | 162 | 20.00 |
| | | | | | | | | | | | | 0.75 | 151 | 20.13 |
| 20 | 50 | 157.1 | 20 | 100 | 314.2 | 20-mm KDP | 510.6 578.2 | 271.2 | 18 | 100 | 56 | 20.50 | 402 | 1.96 |
| 20 | 50 | 157.1 | 20 | 100 | 314.2 | 20-mm KDP | 578.2 | 289.1 | 18 | 100 | 56 | 7.00 | 483 | 6.90 |
| | | | | | | | | | | | | 3.50 | 251 | 7.17 |

## CONCLUSIONS

**Най-високата средна лазерна мощност на линията 255.3 nm е 1.6 W при средна напомпваща мощност 7.20 W, т. е. ефективността на честотното преобразуване е 22.2 %, докато максимална ефективност на честотно преобразуване 34.3 % се достига при средна УВ лазерна мощност 144 mW и средна мощност на напомпване 0.40 W.**

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