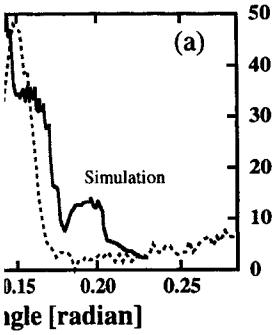

· pump energy in the simulation,

itudinal laser with molybdenum
ved in experiments is found to be
intensity lower than that used in
iform intensity distribution of the
results also show that a relatively
: this novel scheme.

., Sandner W., *Phys. Rev. Lett.* **78**

,Stewart R.E., *Phys. Rev. Lett.* **80**

M., Hazi A.U., H. Medecki, B. J.
'., Hawryluk A.M., Kauffman
'.A., *Phys. Rev. Lett.* **54** (1985)

C., Key M.H., Lewis C.L.S.,
J.S., Wolfrum E., *Phys. Rev. Lett.*

1115-1117
'102
ıct. Mater. **33** (1996) 281-284
4) 179-186
Commun. **81** (1991) 54-58

J. Phys. IV France **11** (2001)
© EDP Sciences, Les Ulis

Generation of highly ionized cadmium plasma columns for a discharge-pumped Nickel-like Cd laser

M. Frati, F.G. Tomasel, B. Bowers, J.J. Gonzalez, V.N. Shlyaptsev[1] and J.J. Rocca

Department of Electrical and Computer Engineering, Colorado State University, Fort Collins, CO 80523, U.S.A.
[1] *University of California Davis at Livermore, Livermore, U.S.A.*

Abstract. We report the observation of strong line emission from Ni-like Cd ions in a capillary discharge plasma. Spectroscopically pure Cd vapor was produced in a room temperature environment utilizing a capacitive discharge. The metal vapor was injected into a capillary channel where it was subsequently excited with fast current pulses of up to 200 kA. These results open the possibility of observing laser amplification in the $3d^9 4d$-$3d^9 4p$ line of Ni-like Cd at 13.2 nm and in laser lines of other Nickel-like ions in a discharge-created plasma.

Large amplification in capillary discharge-pumped ultrashort wavelength lasers has been achieved in several elements at wavelengths ranging from 46.9 nm to 60.8 nm [1-3]. In particular, a tabletop Ne-like Ar laser operating at 46.9 nm has produced the highest average power reported to date from a soft x-ray laser, 3.5 mW [4]. This laser has been successfully utilized in numerous applications [5]. There is significant interest in extending the operation of these practical discharge-pumped collisional soft x-ray lasers to shorter wavelengths. This will require, in most cases, the use of lasing materials that are solid at room temperature. We have previously demonstrated that it is possible to generate large amplification in capillary discharge sulfur plasmas generated by ablation of solid sulfur [2]. However, the extension of this scheme to significantly shorter wavelengths requires the excitation of plasmas produced from elements heavier than argon and much larger discharge powers. For this purpose, we have developed a high power capillary discharge designed to generate the hotter and denser [6]. This pulsed power generator, that consists of three pulse-compression stages, produces pulses of up to 200 kA with a 10-90% risetime of typically 12-14 ns. In this paper we discuss progress in the generation of highly ionized cadmium plasma columns for amplification in Ni-like Cd. In this scheme Cd vapor is generated by a secondary pulsed discharge and is injected into the capillary channel where is excited by a fast current pulse. XUV spectra of capillary discharge Cd plasma columns excited by 170-200 kA current pulses show dominant emission from Cu-like and Ni-like ion lines. Emission from $3d^9 4d$-$3d^9 4p$ Ni-like Cd lines has been observed. These results suggest a high power capillary discharge might be capable of exciting a Ni-like Cd laser operating in the $3d^9 4d\ ^1S_0$-$3d^9 4p\ ^1P_1$ transition at 13.2 nm.

The plasma columns were generated exciting a capillary channel filled with Cd vapor with the fast current pulse produced by a pulse power generator consisting of a three-stage pulse compression stages. The pulse generator has been described in a previous publication and consists of a Max generator, a water dielectric capacitor and a Blumlein transmission line [6]. The Marx generator is used to pulse charge the

water capacitor in about 1 μs. In turn, the water capacitor is discharged through an spark-gap filled with SF_6 to charge a radial water Blumlein transmission line in about 0.1 μs. Seven simultaneously triggered spark gaps located in the outer diameter of the Blumlein are used to rapidly discharge the transmission line and produce current pulses with amplitude of up to 200 kA and a risetime of less than 15 ns through the capillary load. The capillary channel is located at the axis of the radial Blumlein. Cd vapor is injected into the capillary throughout the hollow anode electrode of the capillary discharge. All the data reported herein was obtained using polyacetal capillaries with diameters ranging from 4 to 5.7 mm and 2 cm in length. The Cd vapor is produces by a metal vapor gun that was designed to produce metal vapor in a room temperature environment by rapidly heating a cadmium electrode by discharging a capacitor. Figure 1 shows a spectra of the visible/ultraviolet light emitted by the Cd vapor jet produced by this auxiliary discharge. All the strong features in the spectra were identified to correspond to either first or second order of neutral Cd transitions. No significant impurity lines were observed, an indication that the Cd vapor jet produced by this discharge is of a high purity.

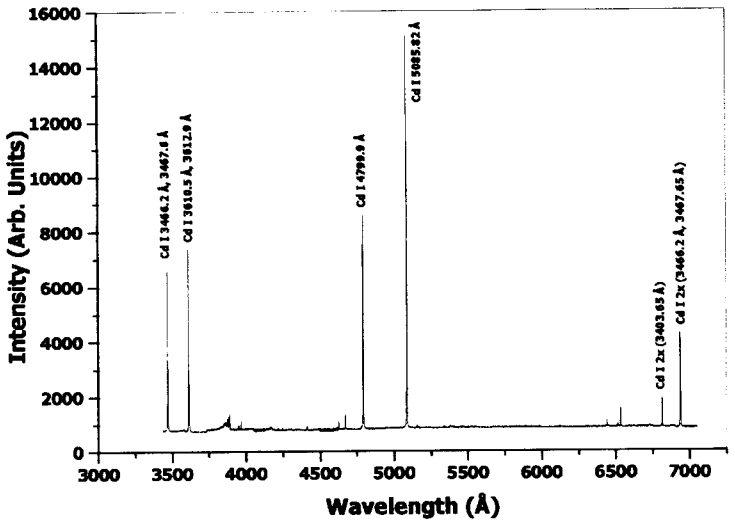

Figure 1. Visible spectra of the emission from vapor produced at room temperature by a capacitively driven discharge containing a Cd electrode. All the lines observed in the 340-700 nm region correspond to Cd I, an indication of the high degree of purity of the metal vapor produced.

End-on spectra of the capillary discharge plasma were obtained using a 2.2 meter grazing incidence spectrograph provided with a with either a 600 or 2400 lines per millimeter gold coated grating. Time resolution of about 5 ns was obtained by gating a multichannelplate intensified detector. Figure 2 shows an spectra of the Cd capillary discharge plasma for the 23-26 nm region. The spectra corresponds to a discharge in a 5.7 mm diameter polyacethal capillary excited by a current pulse of 196 kA peak amplitude. Many of the dominant lines are identified to correspond to the Ni-like and Cu-like ionization states of Cd [7]. All the Ni-like Cd lines in this spectral region are $3d^9 4p$-$3d^9 4s$ transitions. Figure 3 is a spectra covering the 17.2-18.4nm region. In this spectra strong line emission is observed from $3d^9 4d$-$3d^9 4p$ lines of Ni-like Cd at 18.02 and 18.03 nm. This results shows that a fast capillary is capable of

exciting the 4d levels of Ni-like Cd, capable of generating amplification in

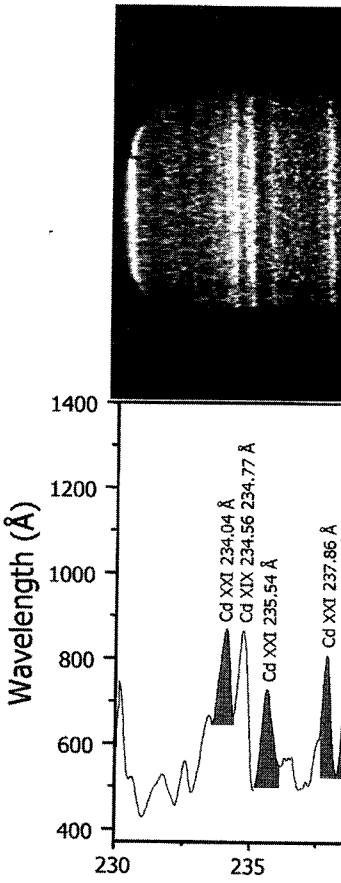

Figure 2. On axis time resolved s
The spectra was obtained 31 ns a

In summary, we have demons
emission from Ni-like Cd ions. Spectr
and injected into a capillary channel w
ray spectroscopy of the capillary disch
lines, including 4d-4p lines. This is the
ionized ions is observed in a capillary
laser amplification in the J= 0-1 4d-4
like ions in a capillary discharge plasm

ged through an spark-gap filled with
μs. Seven simultaneously triggered
o rapidly discharge the transmission
a risetime of less than 15 ns through
adial Blumlein. Cd vapor is injected
lary discharge. All the data reported
ging from 4 to 5.7 mm and 2 cm in
esigned to produce metal vapor in a
ctrode by discharging a capacitor.
the Cd vapor jet produced by this
ified to correspond to either first or
were observed, an indication that the

t room temperature by a capacitively
in the 340-700 nm region correspond
produced.

l using a 2.2 meter grazing incidence
millimeter gold coated grating. Time
e intensified detector. Figure 2 shows
region. The spectra corresponds to a
y a current pulse of 196 kA peak
to the Ni-like and Cu-like ionization
$3d^9 4p$-$3d^9 4s$ transitions. Figure 3 is a
ne emission is observed from $3d^9 4d$-
ws that a fast capillary is capable of

exciting the 4d levels of Ni-like Cd, suggesting this type of a high power capillary discharge might be capable of generating amplification in the 4d-4p line of Ni-like Cd at 13.2 nm.

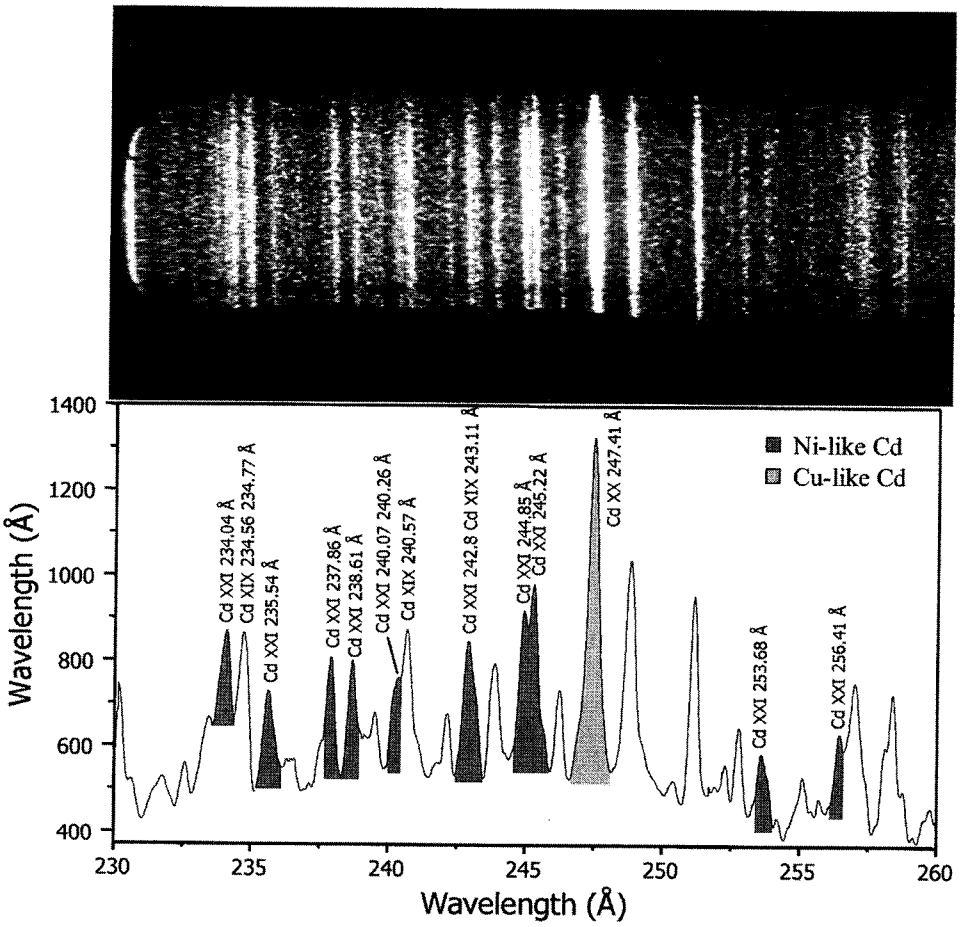

Figure 2. On axis time resolved spectra of a Cadmium capillary discharge. The peak current was 196 kA. The spectra was obtained 31 ns after the beginning of the current pulse.

In summary, we have demonstrated that a fast capillary discharge is capable of exciting line emission from Ni-like Cd ions. Spectroscopically pure Cd vapor was produced by a secondary discharge and injected into a capillary channel where was excited by fast current pulses of up to 200 kA. Soft x-ray spectroscopy of the capillary discharge plasma identified line emission from numerous Ni-like Cd ion lines, including 4d-4p lines. This is the first time to our knowledge that line emission from twenty times-ionized ions is observed in a capillary discharge plasma. This results open the possibility of observing laser amplification in the J= 0-1 4d-4p line of Ni-like Cd at 13.2 nm, and in laser lines of other Nickel-like ions in a capillary discharge plasma column.

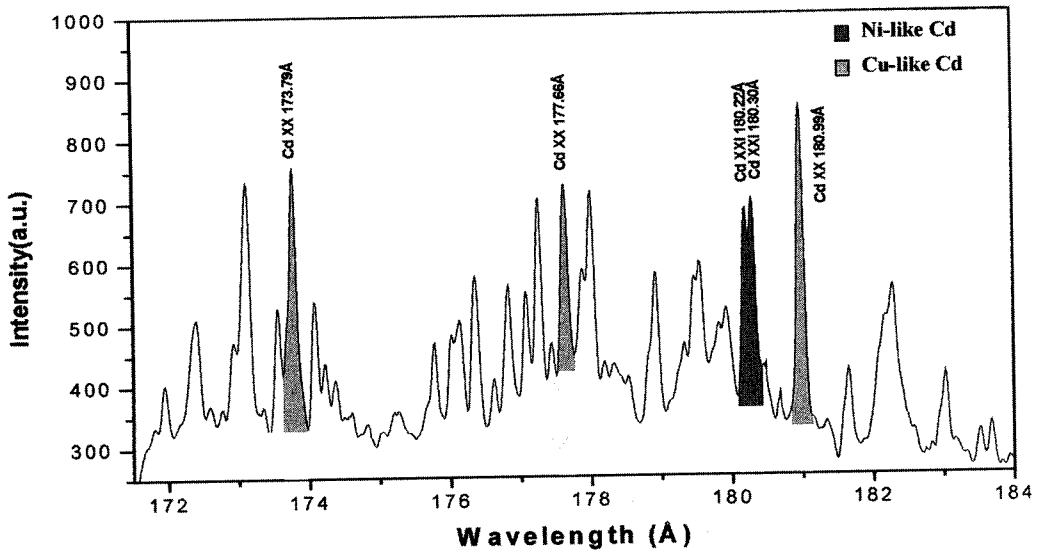

Figure 3. Time resolved spectra of Cd capillary discharge in the 17.2-18.4 nm region. Line emission from the 4d- 4p lines of Ni-like Cd at 18.02 and 18.03 nm is observed. The capillary diameter was 5 mm

This work was supported by DARPA and by the National Science Foundation. We also gratefully acknowledge support from the W.M. Keck Foundation.

References

[1] J.J. Rocca, V. N. Shlyaptsev, F.G.Tomasel, O.D.Cortazar, D. Hartshorn, J.L.A. Chilla, Phys. Rev. Lett., **73**, 2192, (1994); J.J. Rocca, D.P.Clark, J.L.A. Chilla, and V.N. Shlyaptsev, Phys. Rev. Lett. **77**, 1476, (1996).

[2] F.G. Tomasel F.G., J.J.Rocca., V.N. Shlyaptsev, and C.D Macchietto. Phys. Rev. A **55**: (2) 1437 (1997).

[3] M. Frati, M. Seminario, and J.J. Rocca.. Opt. Lett. **25**, 1022 (2000)

[4] C. Macchietto, B.R. Benware and J.J. Rocca, Opt. Lett. **24**, 1115, (1999)

[5] J.J. Rocca et al. "Applications of high repetition rate tabletop soft x-ray lasers become a reality in several fields", in these proceedings; I.A. Artioukov et al. "The prospects of reflectometry and elipsometry with Colorado State University Table-Top XUV Laser, in these proceedings.

[6] J.J. Gonzalez, M. Frati, Rocca J.J. and V.N. Shlyaptsev, Procc. 6th International Conference on X-ray Lasers, Kyoto, Japan, 163, (1998); and "Soft X-Ray Lasers and Applications III, SPIE vol. 3776 159, 1999.

[7] S.S. Churilov, A.N. Ryabtsev, and J.F. Wyart, Phys. Scripta **38**, 326 (1988).

J. Phys. IV France **11** (2001)

A study of electrical dis

M. Vrbová, A. Jancárek, L. P
and L. Nádvorniková

*Czech Technical University, Facu
Czech Republic
[1] Institute of Plasma Physics, AS
[2] Institute of Theoretical and Expe
Russia*

Abstract. A fast electrical disch
and realized. Steady state discha
of the IONMIX code results. S
various experimental conditions
evaluated macroscopic parameter

1. RECOMBINATION PUMP

We carry on a research of x-ray l
electrical capillary discharge [1,2,3
polyethylene $(CH_2)_n$ or polyacetal (C
discharged through it. The wall mat
electrical current passing through it a
radiation.

To achieve a gain coefficient G >
energy level should be $N_u > 2.2 \times 1$
[4]. To prevent the collisional mix
density should not exceed the value
density should be approximately equal

The primary laser pumping proce
fully stripped carbon ions and electr
temperature be high enough to get hig
the other hand, the efficient three-bo
$T_e^{low} < 30 \div 40$ eV. Thus, an ideal pu
plasma electron temperature from T_e
computer model of carbon plasma clai

2. EXPERIMENT

Polyacetal 2.5 cm long capillaries wit
energy is stored in a bank of 2 - 6 ca
two circular flat plates providing a lo
is 40 kV, so that up to 12 J could be st
to 300 J.cm^{-3} of the delivered energy
created between the coaxial electrod
discharge decreases very quickly and
described as an under-dumped resonan
forms measured for 15 and 5 nF capac
times are 36 ns and 26 ns and the curre