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R. Mohan Sankaran
Konstantinos P. Giapis
Mohamed Moselhy
Old Dominion University
Karl H. Schoenbach
Old Dominion University

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Argon excimer emission from high-pressure microdischarges in metal capillaries

R. Mohan Sankaran and Konstantinos P. Giapis
Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, California 91125

Mohamed Moselhy and Karl H. Schoenbach
Physical Electronics Research Institute, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, Virginia 23529

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We report on argon excimer emission from high-pressure microdischarges formed inside metal capillaries with or without gas flow. Excimer emission intensity from a single tube increases linearly with gas pressure between 400 and 1000 Torr. Higher discharge current also results in initial intensity gains until gas heating causes saturation or intensity drop. Argon flow through the discharge intensifies emission perhaps by gas cooling. Emission intensity was found to be additive in prealigned dual microdischarges, suggesting that an array of microdischarges could produce a high-intensity excimer source. © 2003 American Institute of Physics. [DOI: 10.1063/1.1632034]

Microhollow cathode discharges (MHCDs) are high-pressure microdischarges formed in holes [inside diameter (i.d.) \( \sim 100 \) \( \mu \text{m} \)] drilled in thin metal-dielectric-metal films. These discharges can operate stably at pressures exceeding 1 atm while sustaining a large concentration of high-energy electrons. These two characteristics make microdischarges attractive as a source of excimer radiation which requires three-body collisions of excited atomic states. Indeed, excimer emission has been observed in microdischarges of Ne, Ar, and Xe, ArF, XeCl, and XeI. Limited enhancement in excimer intensity from single MHCDs has been achieved by increasing gas pressure. Larger gains in emission intensity could be obtained more readily by increasing the total plasma volume, a difficult task with these inherently planar devices. Significant gains in excimer intensity could enable fabrication of cw excimer microlasers.

Since high-energy electrons in MHCDs are generated in the cathode fall, a thicker cathode electrode with a deeper hole should automatically provide larger cathode area. Metal capillaries offer an easy solution to fabricating such a device with more internal (cathode) area for plasma expansion. Microdischarges in capillaries can still be operated in the hollow cathode mode and have been used as microreactors for three-body collisions of excited atomic states. Indeed, excimer emission has been observed in microdischarges of Ne, Ar, and Xe, ArF, XeCl, and XeI. Limited enhancement in excimer intensity from single MHCDs has been achieved by increasing gas pressure. Larger gains in emission intensity could be obtained more readily by increasing the total plasma volume, a difficult task with these inherently planar devices. Significant gains in excimer intensity could enable fabrication of cw excimer microlasers.

The experimental set-up for striking microdischarges in capillary tubes bears similarities with that of MHCDs, as shown in Fig. 1. The electrodes consist of a stainless steel capillary tube (cathode), a metal grid (anode), and a sapphire spacer washer. VUV spectra were collected from the anode side. Connection to the dc power supply was through a current limiting resistor \( (R=100 \text{ k}\Omega) \).
atomic oxygen and carbon states. The current was held constant at 4 mA. OI and CI refer to lines corresponding to atomic oxygen and carbon states (impurities).

heating ensued (Fig. 3). At 1000 Torr, the optical power which was obtained by integrating the spectra from 115 to 155 nm, increased with current up to 6 mA and then saturated (Fig. 3). At lower pressures, a maximum was reached at smaller discharge currents followed by a drop in emission, which is attributed to heating ensued.

Cooling of the discharge should be more efficient when gas is flown through the cathode tube (back-flow). Figure 4 shows emission spectra obtained from an argon microdischarge as a function of the flow rate. The discharge was operated at an ambient pressure of 1000 Torr and a current of 4 mA. More intense excimer emission was observed at larger flow rates. Unlike the emission spectra for cross-flow of the gas (Fig. 2), lines from oxygen and carbon contamination were indiscernible even for the lowest flow rate. The absence of emission lines from contaminants is attributed to reduced outgassing due to more efficient cooling. The concomitant increase in the intensity of the excimer emission continuum with flow rate corroborates the role of gas heating and its adverse effect on excimer emission.

Our experiments in single capillary microdischarges suggest that gains in excimer emission intensity are limited despite the dependence on discharge current, gas pressure and flow rate. The positively sloped current-voltage dependence (Fig. 3) indicates operation in the abnormal glow discharge mode. Although the tube geometry provides abundant cathode surface for the plasma to expand, the desired higher discharge current must still pass axially through the tiny tube cross-section. We speculate that the ensuing intense heating (the tube tip can turn red-hot) enhances electron emission at the tube end thus limiting plasma expansion.

An alternative scheme for intensifying the on-axis excimer emission while avoiding heating is to operate aligned arrays of identical microdischarges. The same voltage drop across each tube would sustain a fixed current through the array. The current would be adjusted for maximum excimer emission while minimizing heating problems for a single microdischarge. We tested this idea by introducing a tube segment (5 mm long) between the cathode and the anode of a single microdischarge (see inset, Fig. 5). The supply voltage was increased to permit two discharges to form: two identical plasma potentials must be maintained. Since the current was kept low, tip heating was not excessive and the plasma expansion was not impeded. The total discharge volume was thus doubled. To determine the difference in excimer emission between a single-tube and dual-tube setup, the two discharges were operated sequentially. First, a single discharge was formed in tube 1 (grid is anode); second, a single discharge was formed in tube 2 (tube 1 is anode); finally, both discharges were formed simultaneously (grid is anode, tube 1 is floated). In Fig. 5 we compare spectra for the three cases, collected through a 0.2×10 mm slit located 6 mm away; the ambient pressure and discharge current were 1000 Torr and 4 mA, respectively. We find that discharge 1 is about five times more intense than discharge 2. Assuming that these discharges are an assembly of identical point sources extending...
Excimer emission has been studied in high-pressure argon microdischarges formed in metal capillary tubes. Emission intensity was found to increase with discharge current, ambient pressure, and argon flow rate through the discharge. However, the intensity gains were limited by gas heating. The additivity of excimer intensity from prealigned dual microdischarges—operated simultaneously at a current such that the intensity of a single discharge is maximum—suggests a scheme for fabricating a source of intense excimer radiation that could lead to a dc excimer microlaser.

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FIG. 5. Argon excimer emission spectra from single-tube and dual-tube microdischarges operated in a sequence described in the text. The inset illustrates the setup schematic. The single-tube discharge was operated at a current of 4 mA and voltage of 210 V; simultaneous operation of the dual-tube was obtained at a current of 4 mA and voltage of 420 V.

2–3 mm into each tube, geometric considerations suggest that the intensity difference should be a factor of three. Since the front discharge (closer to the monochromator) can be viewed off axis, we expect more light to be collected from discharge 1 through the rectangular slit. The excimer intensity of the dual discharge setup is approximately equal to the sum of the intensities from the individual discharges for pressures between 600 and 1350 Torr (not shown).