Observation of net gain in the yellow band of K$_2$ excimer by electron-beam pumping

Da Xing$^{a,b}$, Qi Wang$^b$, and Shi-ci Tan
Institute of Laser Life Science, South China Normal University, Guangzhou 510631, People’s Republic of China

Ken-ichi Ueda
Institute for Laser Science, University of Electro-Communications, Chofu, Tokyo 182, Japan

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The design of a high-temperature cell appropriate for an electron-beam transverse pump of alkali dimer excimer lasers is described. By using the cell, an amplified spontaneous emission and a maximum net gain coefficient of 3% cm$^{-1}$ of the K$_2$ yellow band (574 nm) were observed from the e-beam-excited mixture of K/K$_2$ vapor with argon buffer gas. The dissociative recombination of K$_3^+$ is discussed as an efficient formation process of the upper state by the electron-beam pumping.

There has been a considerable number of studies on alkali metal vapor dimers, with interest in developing such excimers as possible sources of tunable, efficiency, and high-power lasers.$^{1-6}$ Optical pumpings have primarily been used as pumping sources because they are easily compatible with the experimental geometry’s which require heated metal vapors. In particular, Bahns and Stwalley$^7$ have reported an observation of small signal gain in the violet band of Na$_2$ by Kr$^+$ laser pumping. Recently, the bound-free emissions (2$^3$$\Pi_u$ → 1$^3$$\Sigma_u^+$) of Na$_2$ violet, K$_2$ yellow, and Rb$_2$ orange bands have been successfully observed by electron-beam pumping.$^{8,9}$

Electron-beam excitation is an efficient means of conventional rare-gas-involved excimer excitations, and this excitation method is capable with producing high pumping power densities and large pumping volumes. Also, we have confirmed its usefulness in the excitation of various metal vapor excimer transitions.$^{8-10}$ In such studies, however, a necessary cold zone which separates the hot vapor zone from the output window of the electron-beam equipment introduces an extra energy loss because of a longitudinal pumping scheme.$^{8,9}$ A transverse excitation scheme simplifies the experiment (such as absorption or gain measurement) by avoiding the complications of coupling both the electron beam and the laser probe beams; and observation of laser oscillation by using an optical cavity at the two ends of the cell. Also, this scheme does not require the intense magnetic guiding fields that are necessary for longitudinal excitation. In this letter we report a design of a high-temperature cell appropriate for electron-beam transverse pumping of alkali dimer excimer lasers; and a measurement of small signal gain coefficients of the K$_2$ yellow band (574 nm) by electron-beam pumping.

A cross-sectional view of the vapor cell coupled to the electron-beam machine is shown in Fig. 1. The cell consists of the electron-beam-pumped region, shaped as a half cylinder with a diameter of 5 cm and 20 cm long, and two water-cooled end tubes separating the pumped region from the windows. The end tubes have an inner diameter of 3 cm and 12 cm long. The half-cylindrical region is welded to a backplate with a rectangular opening for coupling the electron beam into the cell. A steel wick is incorporated in the cell to provide recirculation as in standard heat pipes. To prevent condensation of the alkali metal vapor the cell remains at approximately 30 °C hotter than the alkali reservoir. This is very important to control the uniformity of the alkali vapor density and suppress the cluster formation in the cell. The body of the cell is constructed by a type of 316 stainless steel. It has a sufficiently high tensile strength even at a high-temperature of 700 °C; and a corrosion resistance (particularly against reactants such as alkali metals).

The Inconel foil with 30 μm thickness seals the rectangular-shaped opening (14×2.8 cm) of the half-cylindrical heated region of the cell. The foil has to be capable with high temperatures and pressures, and yet still allow electron-beam penetration into the cell. To solve the difficulty of cell sealing, we designed a knife-edge groove in the backplate around the opening to mate with a copper gas-
The range of 535–615 nm consisted of several sharp potassium atomic lines and a broad continuous molecular band. The band spread from 545 to 580 nm and showed good coincidence with that observed in the optical pumping,1,5 and the previous electron-beam pumping.9 The broad emission centered at 574 nm has been identified as the K2 triplet band \( 2^3\Pi_g \rightarrow 1^3\Sigma^+ \) bound-free transition.1 This will be abbreviated as the K2 yellow band in the remaining part of the letter. The emission spectrum exhibits a 7 nm wide peak and a blue-shaded diffuse feature spreading to 545 nm. Both of these are in good agreement with a previous theoretical calculation using the \textit{ab initio} potentials given by Krauss and Stevens11 and Jeung and Ross.12

The behavior of the 574 nm transition was investigated as a function of the excitation energy density by varying the input electron particle energy. The observed excitation energy dependence of the bound-free 574 nm emission is given in Fig. 3. In the lower pumping energy, the intensity of the yellow band almost linearly increases with the increasing of the pumping energy. An emission enhancement of the 574 nm and a narrowing of the spectrum were observed when the excitation energy density exceeded 10 mJ/cm\(^2\), which showed a phenomenon of amplified spontaneous emission.

The effective gain coefficient of the yellow band at 574 nm was investigated by two methods. The first one used a probe light beam into the cell and directly measured the spectral intensity increase of the output beam.7 In this case the beam was well collimated and was spectrally broad with a diameter of 5 mm at the center of the cell and a beam divergence of 8 mrad. The second method introduced a colli-mated back mirror and then measured the intensities of the yellow band spectrum with and without the mirror. For this case the net gain-length product \( \gamma L = L [I_{\text{with}} / I_{\text{without}}] - 1 \). Because of thermal convection, a light-scattering loss was measurable at the conjunction parts between the hot and cooling zones. The effective gain-length \( L \) should be a little smaller than the length of the pumped zone, which was \( \sim 12 \) cm. In the present experimental conditions, \( L \) was estimated to be 10 cm. This was supported by a fitting calculation using the absorption density measured at the K resonance line, as well as the vapor density calibrated by the absorption linewidth at the heat-pipe condition as discussed above.

The results from the two different observing methods show a coincidence within a 20% variation. However, due to the distance of the observing point to the center of the cell
heat caused the reaction energy is greater than the dissociation limit of \( K_3^+ \) bound sites. Thus, resulting in a paired dissociation to \( K_3^+ + K \). This reaction provides a mechanism for selective production of a variety of highly excited diatomic states. Process (1) is predicted to have a large cross section because it is near resonant in reaction energies \([\Delta E] = 0.28 \text{ eV} \) (Ref. 14).

As discussed elsewhere,15,16 this mechanism is particularly attractive in that the ionization is not a serious loss but rather an integral part of the pumping, and the predominant ions in the alkali vapors are trimer ions. For example, at 430 °C (about 10 Torr, saturated vapor pressure),

\[
P(K_3^+)/P(K_2^+)/P(K^+) \approx 99:1:1
\]

by a theoretical estimation.16 Thus, the upper state of such a specific excimer transition may be produced selectively by a dissociative recombination process subsequent to very nonselective ionization. For this reason, the potential alkali dimer laser might be realized by such an efficient excitation process.

In conclusion, we report an observation of optical gain in \( K_2 \) yellow diffuse bands by electron-beam pumping. The strong continuum emission centered at 574 nm is confirmed to be attributed to the \( K_2 \) \( ^3\Pi_g^+ \rightarrow ^1\Sigma_u^+ \) bound-free transitions of \( K_2 \). For pumping intensity above 10 mJ/cm\(^2\), an amplified spontaneous emission of the yellow band and a net gain of \( 0.33 \pm 15 \text{ cm}^{-1} \) was observed in the present experiment. This value should be further increased by the addition of the pumping power density; and by the optimization of the cell geometry and the operating condition.

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\[ K_3^+ + e^- \rightarrow K_3^{+*} (\text{unstable}) \rightarrow K + K_2 \left( ^3\Pi_g^+ \right). \]