Distributed-Feedback KCl:N2 Color Center Lasers Operating in the 1300 nm Region

Distributed-Feedback KCl : N_2 Color Center Lasers Operating in the 1300 nm Region

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We report on a distributed-feedback (DFB) color center laser based on N_2 centers in KCl. A periodic grating with fringe spacings as fine as 440 nm was produced by means of a two-photon coloration process using two interfering beams. Coloration and photoaggregation processes and the DFB laser action can be availed by the fourth- and second-harmonic and the fundamental lines of a Q-switched Nd : YAG laser, respectively. The linewidth of the DFB output is less than 0.3 nm in the spectrally important 1300 nm region.

The stable, tunable, pulsed laser action of multi-electron systems based on the N_2 center in additively colored KCl has been demonstrated previously.1) The laser shows long-term operational stability and tunes smoothly from 1230 to 1350 nm when pumped by a 1064 nm Q-switched Nd : YAG laser at 10 kHz repetition rates.

In most alkali halides the N absorption bands are situated at the longest wavelengths of all the absorption bands of various color centers. The N bands consist of N_1 and N_2 bands, the former located at a shorter wavelength than the latter. Although many investigations have been made on some optical and thermal properties of these centers, much of the ambiguity is still unresolved.2-5)

The N_2 center is usually produced in alkali halides at room temperature by means of both coloration and photoaggregation processes. Therefore, if interfering beams are used in one of these processes, it will be possible to write permanent periodic gratings into the crystals. This is the basic idea in this work. In order to realize this idea, the following technique was used. In the first step, the KCl crystal was colored by a two-photon process6) using two interfering beams. As a result, the periodic F center grating was produced. In the second step, the periodic F center grating was transformed into the laser-active N_2 center grating by exposing the crystal to the F band light.

In this letter, we report the preliminary experimental results of this technique applied to a KCl N_2 center laser. This is the first demonstration of a distributed-feedback (DFB) KCl N_2 center laser in the 1300 nm region. So far, such a DFB color center laser action has been reported using the KCl : Li F_A(II) center laser7) in the 2700 nm region and the LiF F_2 center laser8,9) in the 680 nm region.

KCl crystals were grown in our laboratory using the Kyropoulos method. Prior to use, a 5×

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15×1 mm^2 slab was cleaved out. One of the two large faces (15×5 mm^2) was optically polished and the two output faces (5×1 mm^2) were freshly cleaved. Coloration was performed by means of a two-photon process developed by Mollenauer et al.(6) using the fourth harmonic (266 nm, 4.66 eV) of a Nd : YAG laser system. They applied such a technique to a KCl : Li F_A(II) center laser in the 2500～3000 nm region for the first time.(7)

In general, alkali halides are normally transparent to the laser photon energy of 4.66 eV. However, the magnitude of the two-photon energy is well within the fundamental absorption edge of some of the alkali halides except for LiF. A sample of KCl, whose first absorption peak occurs at 7.50 eV,(10) was visibly colored by exposure to 266 nm radiation at a high power density.

A simple interferometer of Fig.1, designed by Mollenauer and Tomlinson,(11) was used to write the gratings. It consists of beam splitter (BS) and plane mirrors (M1, M2 and M3). Mirror M0 plays a vital role, even though it is not part of the interferometer proper. When displaced as indicated by the dashed lines, M0 serves to translate the beam parallel to itself, thus successively illuminating portions of the interference pattern on the crystal. This interferometer enables piecewise generation of precisely registered gratings of arbitrary size by sequential exposure of small segments of the photosensitive medium. This is an important advantage for our two-photon process, since the exposure time necessary to produce a certain level of coloration is proportional to the square of the beam spot area.

The laser used here emits 8 ns pulse width and 6 mJ energy per pulse at 10 Hz repitition rates at 266 nm. The two interfering beams were focused to a spot of 1 mm in diameter at the sample position. The beam splitter and mirrors were 30-mm diam., $\lambda/10$ flats. The interferometer was set up with $\theta=35.2°$, giving a grating period of 439.9 nm. The beams were slowly translated to produce the 1-mm-wide×15-mm-long DFB laser gratings. Each grating exposure took approximately 10 min., involved 6000 pulses of 266 nm radiation. After coloration, the N_2

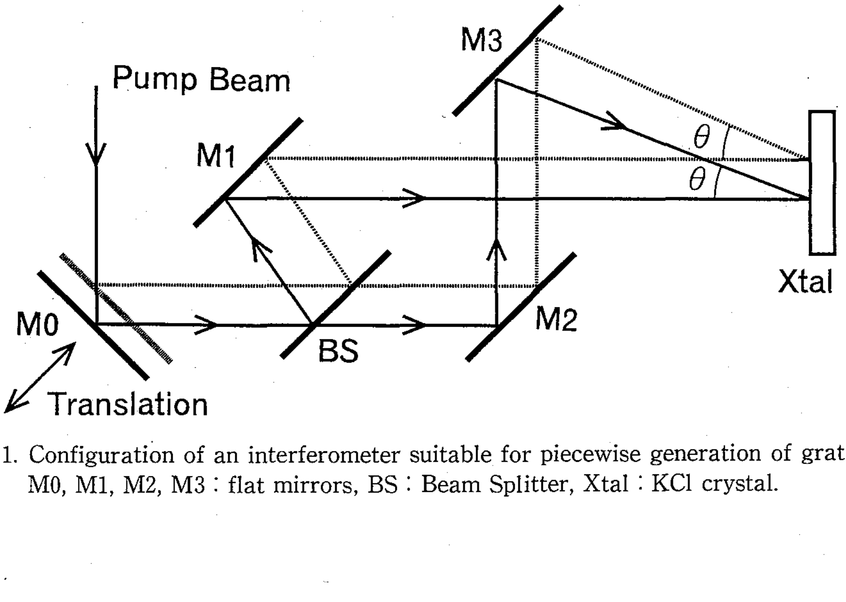

Fig. 1. Configuration of an interferometer suitable for piecewise generation of gratings. M0, M1, M2, M3 : flat mirrors, BS : Beam Splitter, Xtal : KCl crystal.

center and other F-aggregate centers were introduced to the crystal at room temperature by exposing it to light either from a 500 W Xe lamp through appropriate band-pass filters or from the second harmonic (532 nm) line of a Q-swiched Nd : YAG laser. The N_2 band approached saturation values after one hour of F-light exposure at the intensity of 0.5 $W \cdot cm^{-2}$ at room temperature.

Figure 2 shows the typical absorption spectra at 77 K for a KCl crystal doped with different OH^- concentrations, after the two-photon coloration and photoaggregation processes described above. The OH^- concentrations were determined from the intensity of the ultraviolet absorption band at 205 nm.[12] As a result, the OH^- concentrations were estimated to be about 1, 360 and 960 ppm. As shown in Fig. 2, the N_1 and N_2 bands in KCl peak at 970 and 1020 nm, respectively. The N_2 center in KCl overlaps with the 1064 nm line of a Nd : YAG laser, which is used as a pump source.

Figure 3 shows the emission spectra of a KCl crystal doped with 1 ppm OH^- resulting from unpolarized excitation into the R_1 (657 nm), R_2 (730 nm), F_2 (801 nm), N_1 (970 nm) and N_2 (1020 nm) bands at 77 K ; in all the five curves, the emission due to excitation into the N_1 and R_1 bands includes an additional structure on the longer-wavelength side of the R_2, F_2 and N_2 emission bands. All these emission bands peak at approximately 1250 nm. Moreover, the systematic investigation of six different OH^- concentrations from 1 to 960 ppm in KCl indicates that the emission intensity in the 1300 nm region decreases quickly with increasing OH^- concentrations due to overlapping of the absorption bands and losses of re-absorption in the emission region.

The DFB laser action was achieved by placing the sample in a liquid-N_2-temperature

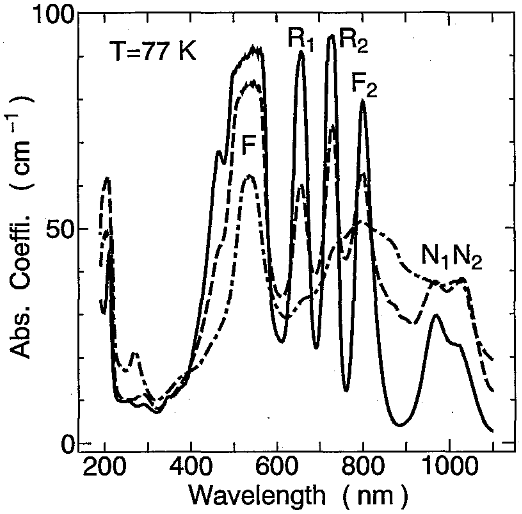

Fig. 2. Absorption spectra of a KCl crystal doped with different OH^- concentrations, after the two-photon coloration and photoaggregation processes. The OH^- concentrations are 1 ppm (solid curve), 360 ppm (dashed curve) and 960 ppm (dash-dot curve).

cryostat and transversely pumping with the 1064 nm line of a Q-switched Nd: YAG laser. The laser beam with an energy of 4 mJ per pulse was focused by a cylindrical lens to realize homogeneous excitation of the entire grating region. The pump powers combined with tight focus caused surface damage to the crystal. The laser outputs were measured with a linear

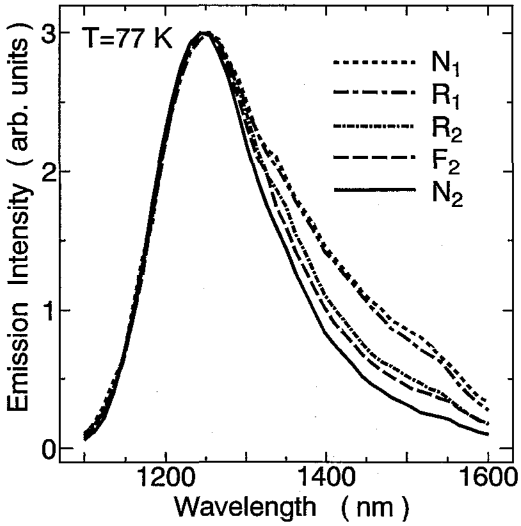

Fig. 3. Emission spectra in KCl doped with 1 ppm OH^- for R_1 (657 nm), R_2 (730 nm), F_2 (801 nm), N_1 (970 nm) and N_2 (1020 nm) excitation. The bands have been normalized to the same height at 1250 nm.

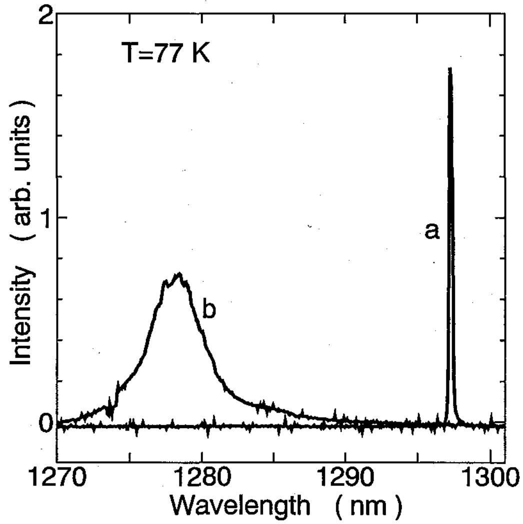

Fig. 4. The DFB output (curve a) and the normal laser action (curve b) without a tuning element in the cavity. These curves were obtained by pumping the N_2 center in KCl with a Q-switched Nd: YAG laser at 1064 nm.

array detector at the image plane of a monochromator.

Figure 4 shows the typical laser outputs of the sample pumped above threshold. The DFB output spectrum at 77 K is compared to the normal laser action using the Fabry-Perot resonator without a tuning element. The linewidth of the DFB output is less than 0.3 nm and within the resolution of our system. The N_2 color center density was estimated, from Fig. 2, to be greater than 3×10^{16} cm^{-3}. Moreover, using the experimentally reported values[1] of the 210 ns lifetime at 77 K and the emission bandwidth of 0.138 eV, we can calculate a gain cross section of approximately 4×10^{-17} cm^2 for the N_2 center in KCl. Therefore, this population of N_2 center, if fully inverted, would have a gain coefficient of about 1.2 cm^{-1} at the band peak. Due to the low gain N_2 center laser, the 15-mm-long crystal was used to increase the product of the gain coefficient and the gain path. Moreover, the experimental value of the oscillation wavelength of 1297 nm is smaller than the theoretical value by 3 nm, calculated from the fringe spacing (439.9 nm) and the refractive index (1.478) of the KCl host for the first-order Bragg reflection. The discrepancy may be attributed to the misalignment of the angle between the two interfering beams. The misalignment angle of 0.1° results in the experimental error of about 3 nm for the oscillation wavelength. The DFB N_2 laser in KCl displayed no power fading during operation at 77 K. Additionally, laser crystals that were warmed, stored at room temperature in the dark for over a week, and reused in the laser without any reprocessing yielded the same output power as when used for the first time.

In conclusion, we have demonstrated the DFB laser action based on the N_2 center in KCl in the spectrally important 1300 nm region. In order to optically write the periodic gratings, a two-photon coloration process using the interfering fourth harmonic of a Nd : YAG laser was used instead of an additive coloration. DFB laser output in the 1300 nm region has been observed with linewidths narrower than 0.3 nm. In the case of the N_2 center in KCl, the coloration and photoaggregation processes and the DFB laser action can be availed by the fourth-(266 nm) and second-(532 nm) harmonic and the fundamental (1064 nm) lines of a Nd: YAG laser, respectively. Moreover, the N_2 center laser operates without the need for auxiliary light sources, in contrast with the $(F_2^+)_H$[13] and $(F_2^+)_A$[14] center lasers require them. At present, the similar experiment using the N_1 center in KBr, whose absorption band peaks at 1070 nm and emission band peaks at 1500 nm, is under way.

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