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An Unstable Laser-Resonator for the 66μm Line of D_2O that exploits the Reststrahlen Properties of KCl

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An Unstable Laser-Resonator for the 66µm Line of D_2O that Exploits the Reststrahlen Properties of KCl

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Intense laser radiation in the 50 - 500µm wavelength range has potential applications for measuring ion temperatures and impurity concentrations in tokamaks.

Following the first demonstration by Chang {1} of optically-pumped far infrared (FIR) laser action in methyl fluoride, laser-like action has been observed in numerous molecular gases, spanning the wavelength range 30µm - 2mm {2}.

In general, the FIR emitting molecule is pumped by a CO_2 laser line in the 9 - 10µm region. The molecule absorbs through a vibrational transition, and laser action occurs by one or more rotational transitions in an excited vibrational state.

The development of these devices has been hampered by the limited number of optical materials suitable for construction. In order to overcome this problem ingenious resonator arrangements have been devised, however, all of these schemes incur serious losses to either the pump or FIR radiation. This problem is particularly acute in the 30µm - 100µm wavelength range. It is in the middle of this region that D_2O vapour has been shown to exhibit very strong emission lines at 50μm and 66μm, when pumped with the 9.66μm line of a CO_2 laser {3}. Apparently, the radiation is produced by stimulated Raman scattering near resonance rather than by stimulated emission alone {4}.

It is the purpose of this Letter to draw attention to the reststrahlen properties of ionic crystals for FIR laser design in general and for use in a D_2O laser emitting at 66μm in particular.

Most ionic crystals have strong reflection bands in the far-infrared region due to lattice vibrations. This high reflectivity corresponds to the frequency band of the ion vibrations in the crystal lattice which interact directly with the light. The term reststrahlen is used for this phenomenon. Furthermore, whilst the best performance is obtained at near normal incidence, even with angles of incidence greater than 50° the characteristics are not greatly changed for most materials.

On examining published data concerning the reflectivities of various ionic crystals {5} we find a fortuitous result. KCl at room temperature has a reflectivity of about 88% at 66μm.

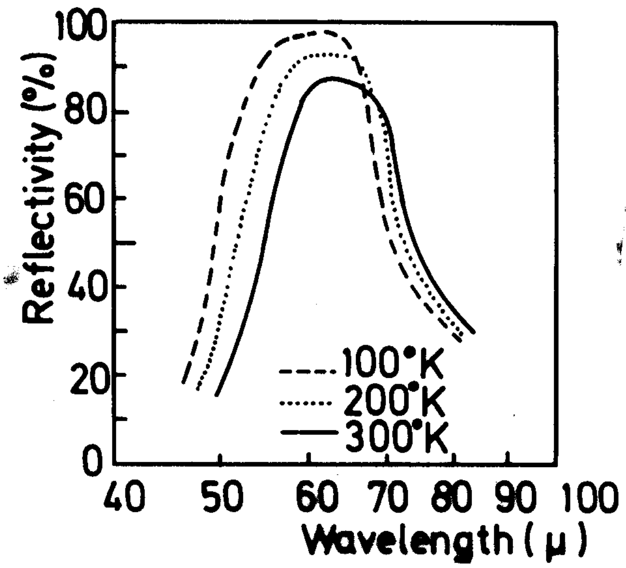


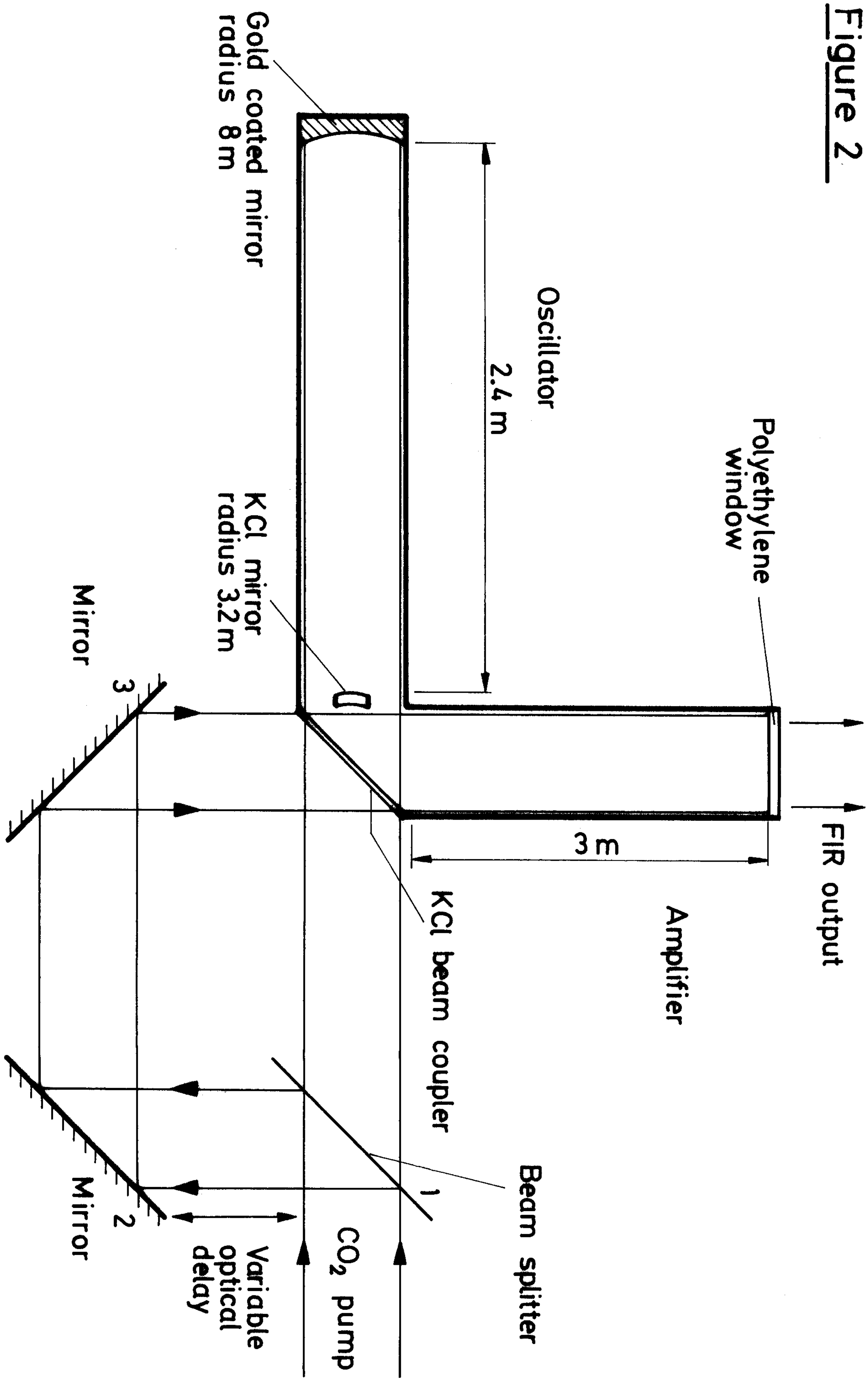
Figure 1. Reflectivities of KCl at low temperatures (Reproduced from Mitsuishi, {5})

This reflectivity is not, by itself, extraordinary as there exist metals with higher reflectivity, e.g. gold 99.5%. However, KCl is transparent to CO_2 laser radiation, and is frequently used for high-power CO_2 laser windows and lenses. This combination of properties can be utilized in FIR laser design. We suggest as an example the following scheme :

For stable, single-transverse mode oscillation from high power, large diameter lasers, the unstable optical resonator offers nearly ideal properties {6}. With such a resonator it is possible to achieve excellent transverse mode discrimination and optimal output coupling using all reflective optics.

The resonator is illustrated in Figure 2. CO_2 pump radiation enters through a KCl plate set at 45^o (Brewster's angle for KCl is about 55^o and as a consequence reflection losses are small). The FIR resonator comprises a 100% reflecting concave mirror (gold plated) and a convex KCl mirror. The reflectivity of the KCl surface is 88%, but the output coupling is selected independently by the mirror size. By fabricating the KCl convex mirror with a concave back surface of equal radius of curvature it is possible to avoid diverging the CO_2 pump beam. Because the KCl mirror is transparent to 10μm radiation the vapour in the resonator is uniformly pumped. An opaque mirror would cast a shadow in the laser and seriously perturb the growth of the single transverse mode in the sensitive central section. If necessary, an amplifier can be incorporated into the design, as illustrated in the figure. Pumping is accomplished as shown. Furthermore, by the use of an external optical delay, the oscillator and amplifier can be pumped at different times, if so desired.

Figure 2


Gold coated mirror
radius 8 m
Oscillator
2.4 m
Polyethylene
window
KCl mirror
radius 3.2 m
Mirror
3
FIR output
3 m
Amplifier
KCl beam
coupler
Beam splitter
1
Mirror
2
Variable
optical
delay
CO_2 pump

One disadvantage of using KCl is that it is hygroscopic. However, the typical working pressure of a D_2O laser is from 1 to 10 Torr and this range corresponds to the normal partial pressure of water vapour in the atmosphere. KCl does not significantly deteriorate if it is exposed to the atmosphere in a normal laboratory environment. Consequently, serious degradation of KCl during its use in a D_2O laser is not anticipated.

To summarize and conclude, we have noticed that due to reststrahlen reflection KCl has a high reflection coefficient at 66μm, apart from its excellent transmission at 9.66μm. These properties make KCl suitable for use in FIR laser construction. This is fortuitous because of the dearth of suitable materials in the 30μm - 100μm wavelength region. Furthermore, in the case of D_2O vapour, the narrow reflection band (∿25μm FW HM) will ensure lasing on the 66μm line alone. The two adjacent lines, at 50.5μm and 83μm and the line at 120μm will all be subject to a much lower feedback in the resonator, and thus will be suppressed. The hygroscopic nature of KCl does not represent a serious impediment to its use.

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