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New Approach for Manufacturing IR Filters Suitable for the Two CO_2 Laser Wavelengths

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Abstract

In the approach of manufacturing infrared filter suitable for filtering CO_2 laser output a new method for selection of CO_2 wavelengths in infrared region has been produced using different chemical compounds. The spectra of three chemical compounds of ZnS, Ca_2F, and KBr, present in different concentrations and different ratios, were measured in the region from 2.5 – 25 µm using IRFT spectrometer. The results were evaluated using WinFITST Lite computer program, which provides the survey of infrared radiation in the same region. The spectra showed high transmission percentage for two mixtures, (Ca_2F and KBr) for wavelength 9.4 µm and the other (ZnS, Ca_2F and KBr) for 10.6 µm only. Then filters were manufactured from these compounds in different thickness and different concentrations in order to be used with the CO_2 laser beam in any desirable wavelength form the two mentioned above plus, with the control of the filter thickness, the transmission percentage can be controlled.

Introduction

The CO_2 is tri-atomic molecule composed of three atoms bonded together. It has three normal modes of vibration: the symmetric stretch mode, the bending mode, and asymmetric stretch mode. Figure (1) shows the condition of theses vibrations. [1, 2]

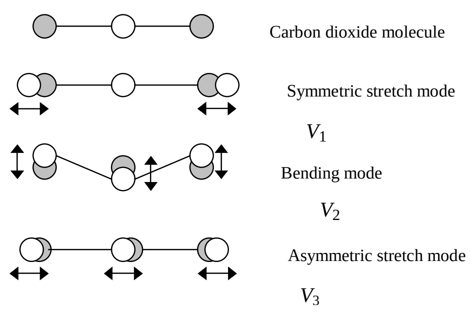

Figure 1: Vibration modes of the CO_2 molecule.

The number of vibration quanta present in each mode of the CO_2 molecules are designated (v_1, v_2, v_3) has v_1 quanta in the symmetric stretching vibration; v_2 is the bending vibration, and v_3 is the asymmetric stretch and the total vibrational energy equal:

$$E_{vib}(v_1,v_2,v_3) = hv_1(v_1+1/2) + hv_2(v_2+1/2) + hv_3(v_3+1/2)$$

Where h is Plank constant. Thus, one quantum in the asymmetric stretch mode is indicated by (001), and the two quanta in the symmetric stretch mode that represented by (200). The series of rotational states of CO_2 laser transition are the (001) to (100) at 10.6 µm transition and the (001) to (020) at transition of 9.4 µm, which are the famous lasing transitions in this molecule. Figure (2) shows the energy levels of CO_2 and the possible laser action.[3]

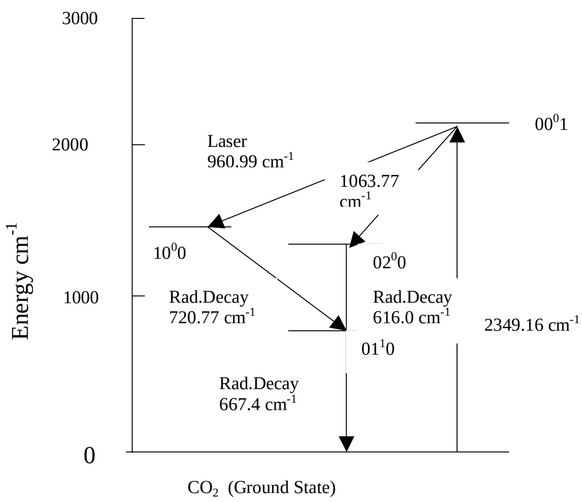

Figure 2: Energy-Levels diagram of CO_2.

The infrared radiation is absorbed in insulators and most semiconductors over the attenuation length, which can be occurs at $L \geq 10^{-4}$ cm. The absorption and transmission ratio in infrared region, both related to free-carrier absorption and transitions to impurity levels. The transmission of infrared radiation through insulating material is a strong function of wavelength, although the absorption arises from vibrational modes of the crystal lattice at which the absorption coefficient, $\alpha \approx 10^2 - 10^4$ cm^{-1} is typical within these bands. [4]

One of the most important problems in dealing with IR radiation is the filtering and the detection tools and processes. One must study the absorption and transmission of radiation through a suitable matter as a function of the used wavelength. [5] A useful measurement of the material thickness required for significant attenuation of incident radiation is given by $L \approx \alpha^{-1}$, where L is the attenuation length. The transmitted intensity, which passes through the material without attenuation, is conveniently described using the concept of absorption coefficient. [6] This attenuation process obeys Lambert`s law:

$$\frac{I}{I_0} = e^{-\alpha t}$$

Where I_0: the intensity of the incident beam.

I: the intensity of the transmitted beam.

α : absorption coefficient.

t: matter thickness.

The radiation from the source, absorbed by atoms of the used matter, is generally in the form of very narrow lines of characteristic wavelength originating from infrared to far infrared range of the spectrum.

In the approach of manufacturing IR filter, suitable for filtering CO_2 laser output, it is important to obtain information concerning the infrared radiation distribution in electromagnetic waves spectrum by using infrared spectrometer, especially for 9.4μm and 10.6μm wavelengths of CO_2 laser.[7,8] For defining the output of CO_2 laser, and in order to select the exact lasing line which is desired in practical application, one need to use a suitable filter that transmit, with very high percentage, only the desired lasing wavelength. In IR region, the optical components take a special interest because of their importance and the complexity in its manufacturing besides its high expensive costs. [9]

Experimental Part

In the present work the absorption and transmission of infrared radiation, in the range of 2.5 μm to 25 μm, were measured for compounds of ZnS, Ca_2F, and KBr in different thickness and different concentrations in order to obtain suitable filters for CO_2 laser output in both 9.4 μm and 10.6 μm.

Samples from the above compounds with different form were prepared to measure their spectra in the desired region using physical per concentration methods. For each compound of interest, numbers of thin and thick samples were prepared by using different concentrations of compounds in powder state, which were used to prepare disc pellet.[10] All samples were prepared from high purity compound (99.98%). Thin and thick samples were prepared in pellet form. In this work samples were classified in thick and thin samples relative to the transmission percentage for more or less than 50%, respectively.[11]

The chemical crystals were crashed in crucible tray to get fine powder, so as to perform transparent disc pellets. The chemical compounds powder samples were formed in circular shape of 25.4 mm diameter using hydraulic pressing machine of load of 10 tones for different thickness. The samples were placed in a vented oven at 100 C^o for one hour until all moistures were removed.

The spectra of the samples were recorded using infrared spectrometer type Sallelitte FTIR. Direct analyses of whole compounds are almost invariably done on thick and thin samples in an infrared spectrometer. The analysis of infrared radiation spectrum is carried out; using a computer program called WinFITST Lite, which is developed for the deconvolution of complex infrared spectra, produced for a Satellite

FTIR system. The characteristic infrared radiation (spectrum) was identified as absorption and transmission percentage and their intensities, which were analyzed by the computer.

As only the peak in the spectrum reflects the intensity of infrared radiation transmitted outside the filter, this may incorporate some means of identifying the transmission percentage after subtracting the background source intensity underlying the peak. Explicit, peak was identified by comparison of the wave number with wavelength of the infrared radiation source.

Thin and thick samples offer optimal accuracy and high transmission in infrared region, because the absorption enhancement corrections remain small and the background due to exciting radiation scattering is limited. Determinations of the peak detected in the samples were relative to the compound concentrations. The intensity is linearly related to the sample thickness, compounds concentration, and compounds ratio within the studied range. The results of the analysis were used to construct infrared filters for CO_2 laser for both 10.6 μm and 9.4 μm wavelengths.

Results and Discussion

Peak transmission percentage was obtained after calibration of infrared spectrometer by using Potassium Bromide sample of purity 99.99% for background correction. The accuracy of the results was crosschecked using infrared spectrometer type Termonico Lite. Figures below show the IR spectrum obtained for 2 minutes IR irradiation passes through the sample with the wave-number in the interval of 10 cm^{-1}. This fact, together with the absence of any enhanced radiation any way, leads to the conclusion that was observed for scattered radiation producing small peaks in the spectrum, in addition to the shift in the background arising from the moisture and IR background.

Figures (3) and (4) display graphically the peak-transmitted intensity of Zinc sulfide and Potassium Bromide mixture. The full-width at the half maximum of the peak recorded at 10.6 μm is 1.5 μm while for the peak at 9.4 μm it is 1.7 μm. Thus, it is likely that we have two types of filters; one is homogenous mixture (Ca_2F and KBr) for 9.4 μm and the other (ZnS, Ca_2F and KBr) for 10.6 μm only. Comparison of the peak transmitted percentage of Ca_2F+ZnS + KBr, in Figure(5), and Ca_2F+KBr, in Figure (6), shows that high transmission is noticed for 10.6 μm in Figure(5) compared to the Figure (6) for 9.4 μm. The comparison of peak absorption in Figure (7) with peak in Figure (8) revealed highest absorption at 9.4 μm rather than peak at 10.6 μm. The average concentration of the compound in the sample, when it compared to corresponding values at the other samples of different thickness, shows highest value for 10.6 μm than for 9.4 μm of the same sample. These IR filters can be used internally in the laser cavity or externally in CO_2 laser system for wavelength selection in order to insure the output wavelength exactly.

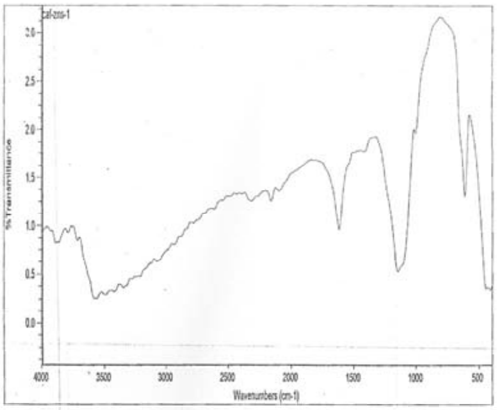

Figure 3

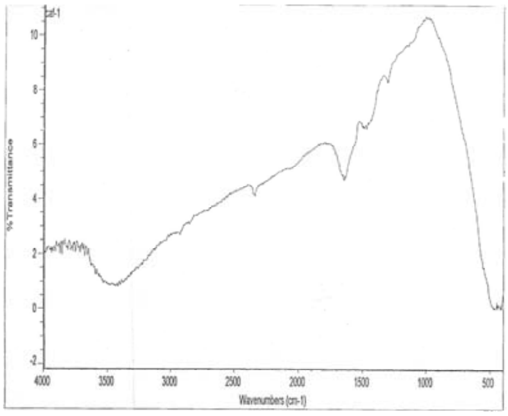

Figure 4

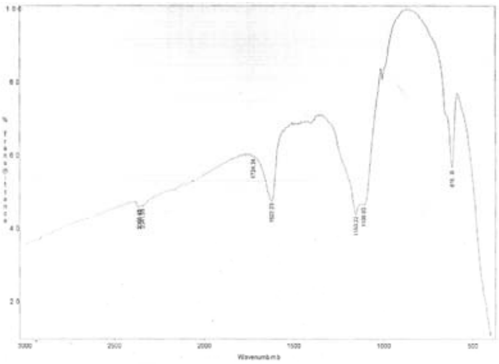

Figure 5

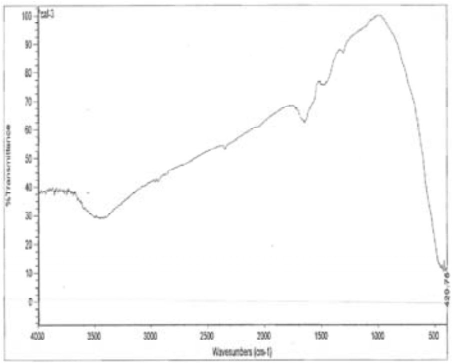

Figure 6

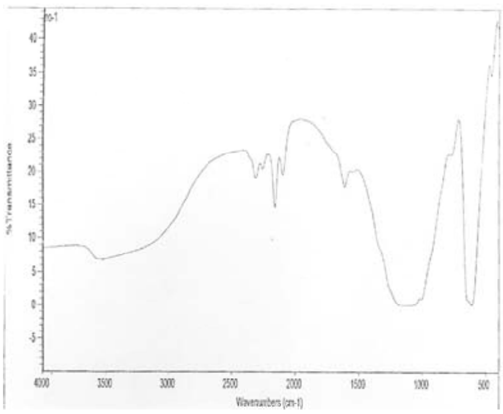

Figure 7

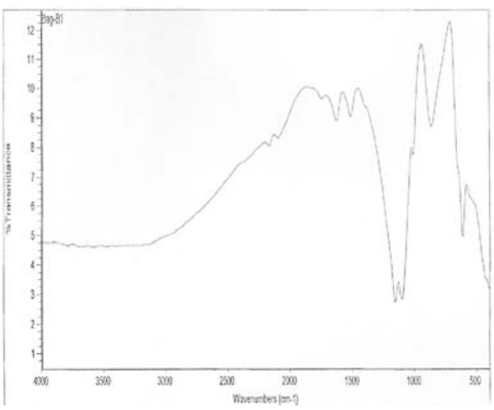

Figure 8

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