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LOCAL OSCILLATIONS IN LiF CRYSTALS WITH HYDROGEN CENTERS

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 Submitted 24 July 1969
 ZhETF Pis. Red. 10, No. 6, 249 - 253 (20 September 1969)

A group of bands in the 4 - 6 μ region was observed in the infrared absorption spectra of LiF crystals exposed to radiation [1]. To explain the nature of the centers responsible for the bands observed in [1], we investigated spectra of crystals with different contents of the hydroxyl ions OH^- irradiated in a reactor and in γ source.

These investigations make it possible to propose the center models listed in the table.

We start the analysis with the 1900 cm^{-1} bands. Calculation based on the formula

$$\omega_L = \{[\epsilon / (1 - \epsilon)](6r_0 / \beta M)\}^{1/2}, \quad (1)$$

where r_0 is the distance between ions, β is the compressibility, $\epsilon = 1 - (M'/M)$, M' is the mass of the impurity ion, M is the mass of the host lattice ion [2]), gives for the local frequency of a tritium U center in LiF a value $\sim 637 \text{ cm}^{-1}$. However, in view of the fact that the transmission limit of LiF, at a sample thickness 1 - 10 mm, lies above $\sim 100 \text{ cm}^{-1}$ [3], the local frequency of the $[\text{T}^{-1}]$ center could not be registered by us.

Absorption band, cm^{-1}	Model of center
2200	H_1^0 - hydrogen atom in interstice (U_2 -center)
2100	H_1^- - negative hydrogen ion in interstice (U_1 -center)
2000	$(\text{H}_2^0)_i$ - hydrogen molecule in interstice
1900	$[\text{T}^-]$ - negative tritium ion in halide site (tritium U-center)

According to [4], a third harmonic of the local oscillation of the U center in alkali halide crystals should be observed. Taking into account the calculation results, according to which the third-harmonic frequency is close to 1900 cm^{-1} , as well as the experimental fact that the band at 1900 cm^{-1} , is observed only in crystals in which the reaction $\text{Li}^6(n, \alpha)\text{T}$ takes place, this band should be ascribed to oscillations of the tritium U center.

Further proof of the proposed model of the centers for the 1900 cm^{-1} band was obtained in experiments in which the irradiation was carried out at low temperatures. The formation of $[\text{T}^{-1}]$ centers should be hindered at lower irradiation temperatures, since the following reactions should take place after the nuclear reaction $\text{Li}^6(n, \alpha)\text{T}$ in order to produce the indicated centers:



Experiments have actually shown that when the irradiation temperature is lowered to 130°K , the band at 1900 cm^{-1} diminishes strongly (see the figure, curves 2 and 3), a fact that should be ascribed to the deceleration of the diffusion processes and to the lowering of the number of tritium U centers, which are the products of reaction (2). The band at 1900 cm^{-1} disappears completely following irradiation with a cadmium filter $\sim 1 \text{ mm}$ thick, which blocks the reaction $\text{Li}^6(n, \alpha)\text{T}$ completely (curve 4 in the figure).

We note that the experimental values of the frequencies of the local oscillations, obtained here for tritium U centers and in [5] for hydrogen U centers, are in very good agreement with the calculated values of the corresponding frequencies obtained by us with formula (1). This can apparently be attributed to the close values of the ion radii of the hydrogen and fluorine. This formula cannot ensure satisfactory agreement in the case of other alkali halide crystals.

Ordinary hydrogen centers can also be produced in LiF crystals irradiated in a reactor or in a γ source, since they always contain hydroxyl ions OH^- , which replace the fluorine ions. As the result of irradiation, the following reaction proceeds vigorously



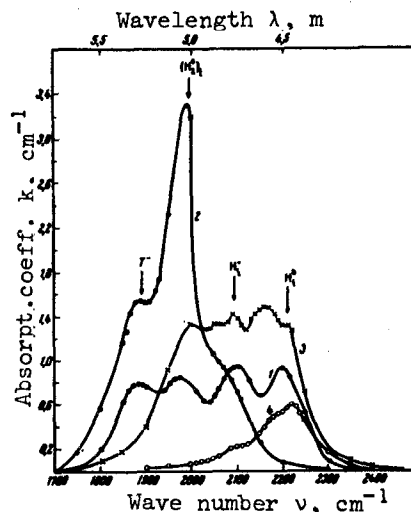
A 2200 cm^{-1} band was produced quite readily in the spectra of the irradiated LiF crystals investigated by us, even at the lowest irradiation doses employed by us. It is natural to assume that it is due to local oscillations of the primary product of the OH^- decay - atomic hydrogen in the interstices. Another primary product, the negative oxygen ion in the halide site, cannot cause the appearance of local oscillations, owing to the insufficient difference between the masses of the oxygen and the fluorine. According to [6], the mass must be reduced by at least the factor of 2 in order for local oscillations to arise.

An increase of the radiation dose increases the probability of the reaction



Experiments have indeed shown that the 2200 cm^{-1} band disappears (see the figure, curves

Infrared absorption spectra of LiF crystals following irradiation with the following doses: 1 - 5.2×10^{16} n/cm², 2 - 1.3×10^{16} n/cm², 3 - 1.0×10^{16} n/cm², 4 - 1.0×10^{16} n/cm², T = 130°K (with Cd filter).



1 and 2) as the result of the H_1^0 . This is accompanied by a strong growth of the 2000 cm⁻¹ band, making it possible to connect it with $(H_2^0)_1$ - molecular hydrogen produced as the result of the reaction (4). This process is controlled by diffusion. The reaction (4) requires thermal energy. When the irradiation temperature is lowered to 130°K, the reaction of the sticking of hydrogen atoms to form molecules is made difficult, so that both bands can be observed.

The fourth of the registered group of bands in the 4 - 6 μ region is the band at 2100 cm⁻¹. We attribute this band to U_1 centers on the basis of the following observations. As seen from a comparison of curves 2 and 3, the 2100 cm⁻¹ band increases, as expected, when the irradiation temperature is decreased, since the probability of formation U centers decreases with decreasing irradiation temperature, as follows from the reactions



and by the same token the probability of formation of the U_1 centers increases in accordance with the reaction



The published data on LiF contain only data for local oscillations of U centers: according to [5], these oscillations correspond to a frequency 1015 cm⁻¹ (we did not register this band, since our sample thickness exceeded 1 mm). However, the frequencies of the local oscillations of the U and U_1 centers are related in a definite manner. This is shown in [7], in which KCl, KBr, KI, and RbCl crystals were investigated, and it was established that the U_1 centers correspond to frequencies that are 1.7 - 1.9 times larger than the frequencies corresponding to the U centers. Inasmuch as the LiF lattice parameter is smaller than the parameter of the crystals investigated in [7], we can assume that for LiF the frequency of the local oscillation of the U_1 center will exceed the frequency of the U center by more than two

times. Thus, inasmuch as the frequency of the local oscillation of the U centers is $\text{LiF} = 1015 \text{ cm}^{-1}$, our band at 2100 cm^{-1} must be ascribed to U_1 centers.

The authors are grateful to Academician E. L. Andronikashvili for stimulating interest in the work.

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SURFACE ELECTROMAGNETIC WAVES IN METALS IN A MAGNETIC FIELD

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Submitted 28 July 1969

ZhETF Pis. Red. 10, No. 6, 253 - 257 (1969)

In 1960, M. Khaikin observed an oscillatory dependence of the surface impedance of metals in weak magnetic fields ($1 - 10 \text{ Oe}$) [1]. Subsequently Nee and Prange [2] explained this phenomenon as being the result of transitions under the influence of a high frequency field between discrete surface levels of electrons moving near the surface of the metal. Under the influence of the magnetic field, the electrons whose orbit centers are outside the metal, are reflected many times from the surface and drift along the surface. The motion of these electrons in a direction perpendicular to the interface is finite and periodic, and therefore can be quantized. Such quantum states have been named magnetic surface states. The impedance oscillations in a weak field actually represent cyclotron resonance on magnetic surface levels. The usual cyclotron resonance [3] due to transitions between Landau levels of volume electrons occurs in a strong magnetic field at frequencies that are multiples of the cyclotron frequency Ω . Since the frequency of transition between surface levels is larger by 2 - 3 orders of magnitude than the cyclotron frequency [2, 4], resonant Khaikin oscillations were observed in weak fields. It must be noted that this phenomenon, as any resonant effect, is a collective phenomenon.

On the other hand, it was established in recent years that collective oscillations -- weakly damped electromagnetic waves -- exist in the vicinity of resonant effects of various types. Examples are cyclotron waves [5, 6] near cyclotron resonances, spin waves in alkali metals near paramagnetic resonance [7, 8], quantum waves in the vicinity of giant quantum oscillations of Landau damping [9, 10], etc. Starting from this, it can be assumed that electronic waves should also exist near resonances on magnetic surface levels. Since the considered quantum states are localized near the surface of the metal, the waves corresponding to them should also be surface waves. We present in this paper the results of a theoretical investigation of this question, and show that such waves actually should exist in pure metals with sufficiently large electron mean free paths ℓ .