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TWO-PHOTON ABSORPTION IN CRYSTALS WITH THE PRESENCE OF ELECTRIC--ETC(U)
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FOREIGN TECHNOLOGY DIVISION

TWO-PHOTON ABSORPTION IN CRYSTALS WITH THE PRESENCE OF ELECTRIC FIELD

by

S. Kh. S"ynov

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FTD -ID(RS)T-1523-80

EDITED TRANSLATION

(14) (11) 24 Nov 80

FTD-ID(RS)T-1523-80 14 November 1980

MICROFICHE NR: FTD-80-C-001123

(6) TWO-PHOTON ABSORPTION IN CRYSTALS WITH THE PRESENCE OF ELECTRIC FIELD, (12) 8

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~~English pages: 5~~

(21) Edited trans. of

Source: Doklady Bolgarskoy Akademii Nauk, Vol. 25, Nr. 3, 1972, pp. 301-303

Country of origin: (USSR) v2 n3 p301-303 1972, by

Translated by: Robert Allen Potts.

Requester: FTD/TQTD

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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
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И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

1523

TWO-PHOTON ABSORPTION IN CRYSTALS WITH THE PRESENCE OF ELECTRIC FIELD

S. Kh. S"ynov.

Submitted by corres. member M. Borisovyy 23 Sept. 1971.

The theory of two-photon absorption was developed by Goppert-Mayer. It was applied to a solid by Braunstein [2] and Loudon [3]. According to [2] the probability of the fact that an electron from a valence zone simultaneously absorbs two noncoherent photons: $\hbar\omega_1$ and $\hbar\omega_2$ and converts into a zone of conductivity is expressed:

$$W=\frac{8\pi^3\hbar e^4 N_1 N_2}{m^4\omega_1\omega_2}\int\frac{d^3k}{(2\pi)^3}\left[\frac{|P_{vn}^{(1)}|^2|P_{nc}^{(2)}|^2}{(E_{nk}-E_{vk}-\hbar\omega_1)^2}+\frac{|P_{vn}^{(2)}|^2\cdot|P_{nc}^{(1)}|^2}{(E_{nk}-E_{vk}-\hbar\omega_2)^2}\right]\cdot\delta(E_{ck}-E_{vk}-\hbar\omega_1-\hbar\omega_2) \quad (1)$$

For case "allowed"-"allowed" transition the matrix element of the moment is written (4).

$$P_{if}=H_{if}(\vec{k}_0)\Phi(0)\delta(\vec{k}) \quad (2)$$

where H_{if} matrix elements, computed with the aid of periodic parts of Bloch functions between corresponding states. In this case they are constants. $\Phi(\vec{r})$ is the solution of Shrodinger equation for electron-hole pair in the presence of electric field $\vec{F}$, if we disregard the Coulomb interaction between them

$$\left[(a_i+a_f)\frac{\vec{P}}{2m}+e\vec{F}.\vec{r}\right].\Phi l(\vec{r})=E_l\Phi_l(\vec{r}) \tag{3}$$

$a_{i,f}$ is the relationship between the mass of free electron and the effective mass in the corresponding zone. Equation (3) is solved in [5] and is used during computation of the coefficient of electric absorption by K. Tharmalingam [6]. According to [4] in cylindrical coordinates

$$E_l=E_z+\frac{\hbar^2k_e^2}{2m}(a_i+a_f) \tag{4}$$

$$\Phi_l(\vec{r})=\beta_{if}\frac{1}{2\pi\hbar}\exp(ik_e\varrho).A_i\left(\frac{-E_z-eF_z}{\gamma_{if}}\right) \tag{5}$$

$$\beta_{if}=\frac{\left(\frac{2m}{a_i+a_f}\right)^{\frac{1}{3}}}{\pi^{\frac{1}{2}}(eF)^{\frac{1}{6}}\hbar^{\frac{2}{3}}} \tag{6}$$

$$\gamma_{if}=\left[\frac{(a_i+a_f)\hbar^2}{2m}\right]^{\frac{1}{3}}(eF)^{\frac{2}{3}} \tag{7}$$

E_z depending on the electric field of energy. $A_i(x)$ Airy function.

For a model with three levels

$$E_{vk} = -a_v \frac{\hbar^2 k_\varrho^2}{2m}$$

$$(8) \qquad E_{ck} = Eg + a_c \frac{\hbar^2 k_\varrho^2}{2m} + E_z$$

$$E_{nk} = \Delta E + a_n \frac{\hbar^2 k_\varrho^2}{2_m} + E_z$$

The absorption coefficient for photon $\hbar\omega_1$ is expressed:

$$(9) \qquad K_1 = \frac{2n}{c} \frac{W}{N_1}$$

After substitution of W from (1) and from (2), (5) and (8) we obtain the following expression for K_1, introducing the density of states:

$$(10) \qquad K_1 = \frac{2^8 n e^4 N_2 \beta_{nc}^2 \beta_{vn}^2 H_{nc}^2 H_{vn}^2}{c m^3 \hbar \omega_1 \omega_2 (a_c + a_v)(2\pi\hbar)^4} \int_0^\infty \int_{-\infty}^\infty \frac{A_i^2\left(-\frac{E_z}{\gamma_{nc}}\right) \cdot A_i^2\left(-\frac{E_z}{\gamma_{vn}}\right)}{\left(\Delta E + \frac{a_n + a_v}{2m} \hbar^2 k_e^2 + E_z - \hbar\omega_1\right)} + $$

$$+ \frac{A_i^2\left(-\frac{E_z}{\gamma_{nc}}\right) \cdot A_i^2\left(-\frac{E_z}{\gamma_{vn}}\right)}{\left(\Delta E + \frac{a_n + a_v}{2m} \hbar^2 k_\varrho^2 + E_z - \hbar\omega_2\right)^2}\Bigg] k_e \, dk_e \, dE_z \, \delta\left(Eg + \frac{a_c + a_v}{2m} \hbar^2 k_e^2 + E_z - \hbar\omega_1 - \hbar\omega_2\right)$$

The absorption threshold is expressed so:

$$(11) \qquad \hbar\omega_1 + \hbar\omega_2 = Eg + E_z + \frac{a_c + a_v}{2m} \hbar^2 k_e^2$$

Having integrated in terms of E_z and set

$$
\begin{gathered}
Eg+\frac{a_c+a_v}{2m}\hbar^2k_v^2-\hbar\omega_1-\hbar\omega_2=\gamma_{nc}t \\
\Delta E+\frac{a_n+a_v}{a_c+a_v}(\hbar\omega_1+\hbar\omega_2-Eg)-\hbar\omega_{1,2}=B_{1,2} \\
\frac{\gamma_{nc}}{\gamma_{vn}}=\left(\frac{a_c+a_n}{a_c+a_v}\right)^{\frac{1}{3}}=\gamma \\
\gamma_{nc}\left(\frac{a_n-a_c}{a_c+a_v}\right)=cp_0
\end{gathered}
\tag{12}
$$

With the aid of (6) and (7) we obtain the following expression for K_1

$$
K_1 \; \frac{2^{6}\pi e^{4}N_2H_{nc}^2H_{vn}^2}{(2\pi\hbar)^{6}mc\hbar^{3}(a_c+a_n)^{\frac{1}{3}}(a_n+a_v)^{\frac{2}{3}}(a_c+a_v)^2\omega_1\omega_2}
\int\limits_{\frac{E_g-\hbar\omega_1-\hbar\omega_2}{\gamma_{nc}}}^{\infty}\left[\frac{1}{(B_1+pt)^2}+\frac{1}{(B_2+pt)^2}\right]A_i^2(t)A_i^2(\gamma t)dt
\tag{13}
$$

As seen from (13) the absorption coefficient K_1 will depend not only on the number of photons $\hbar\omega_2-N_2$, but on the magnitude of the electric field, applied to the crystal. Thanks to this, the absorption can be started with total energy of both photons less than the width of the forbidden zone, similar to single-photon electric absorption. For case

$a_n=a_c(p=0)$ and $\hbar\omega_1+\hbar\omega_2<E_g$

we can use the asymptotic formula of Airy function [5]. Let us substitute it in (3) and obtain

$$
(14) \quad K_1 = \frac{n e^5 F N_2 H_{ec}^2 H_{vc}^2}{(2\pi\hbar)^6 \hbar^2 m^{\frac{3}{2}} c\omega_1 \omega_2 a_c^{-\frac{1}{6}} (a_c + a_v)^{\frac{8}{3}}} \times
$$

$$
\times \left[\frac{1}{(\Delta E - E_g + \hbar\omega_1)^2} + \frac{1}{(\Delta E - E_g + \hbar\omega_2)^2} \right] \cdot \frac{\exp\left[-\frac{4}{3} \left(\frac{E_g - \hbar\omega_1 - \hbar\omega_2}{\gamma_{cc}} \right) \left(1 + \gamma^{\frac{3}{2}} \right) \right]}{\gamma^{\frac{1}{2}} \left(1 + \gamma^{\frac{3}{2}} \right) (E_g - \hbar\omega_1 - \hbar\omega_2)^{\frac{3}{2}}}
$$

Similar to single-photon electric absorption (6) and in this case the absorption coefficient depends exponentially on the energy of photons. *

FOOTNOTE * After this work was sent to press, there became known the work of E. Yang. Opt. Communications. 3, 1971, 6, 421, in which there is examined the problem of two-photon transitions in an electric field and the result is expressed with the aid of Airy function. ENDFOOTNOTE.

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