lay time, which showed the signal phase velocity to be 3.63×10^5 cm/sec.

The frequency f and the phase velocity v of a Love wave are related by the formula[4]

$$f = \frac{v}{2\pi d}\left(\frac{v^2}{v_\ell^2} - 1\right)^{-1/2} \tan^{-1}\frac{\rho_S v_S^2}{\rho_\ell v_\ell^2}\frac{(1 - v^2/v_S^2)^{1/2}}{(v^2/v_\ell^2 - 1)^{1/2}},$$

in which the densities of substrate and layer are denoted by ρ_S and ρ_ℓ. Substrate and layer are assumed isotropic, and the velocities of transverse volume elastic waves in substrate and layer are denoted by v_S and v_ℓ. It is acceptable to assume both YAG and CdS to be isotropic, in which case $v_S = 5.03 \times 10^{-5}$ cm/sec and $v_\ell = 1.87 \times 10^{-5}$ cm/sec; the respective densities are $\rho_S = 4.55$, $\rho_\ell = 4.83$ g/cm^3. Given these quantities, the observed velocity, and the measured layer thickness d, an expected frequency can be calculated. The result is 263 MHz. This is in very good agreement with the observed value of 285 MHz considering the fact that the outer 10% of the layer is aluminum, not CdS.

This work was undertaken to develop a technique for studying UHF surface wave propagation on a variety of substrates. The present results show such a technique to be entirely feasible. In particular, a decrease of comb teeth spacing by a factor of two can be obtained by careful but not sophisticated photoetching methods. Such a decrease can make the 500–1000-MHz region available for study.

It is a pleasure to acknowledge the assistance of W. C. Robinson and R. A. St. Cyr.

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[1] P. Schnitzler, 1968 IEEE Ultrasonics Symposium.

[2] Elastic waves confined to a surface covered by a layer thin compared to propagating wavelength. See, for instance, W. M. Ewing, W. S. Jardetzky, and F. Press, *Elastic Waves in Layered Media* (McGraw-Hill Book Co., New York, 1957) Chap. 4, p. 189.

[3] N. F. Foster, Proc. IEEE **53**, 1400 (1965).

[4] See, for instance, the book cited in Ref. 2.

REFLECTIVITY AND BAND STRUCTURE OF EuO

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Near-normal incidence reflectivity of single-crystal EuO is reported for the energy range 1–9 eV. Results are interpreted in terms of recent band-structure calculations.

Recently much interest has evolved in the intrinsic optical properties and band structure of europium chalcogenides.[1-3] This has followed upon the early discoveries of large magneto-optic effects at low energies in these materials.[4,5]

It is the purpose of this note to report near-normal incidence reflectivity measurements in the range 1–9 eV on single-crystal EuO in its paramagnetic region, and to offer a qualitative explanation of the results in terms of current band structure models. The optical measurements were made on an air-cleaved sample which was then kept at 10^{-6} Torr for the duration of the experiments. Absolute reflectivity measurements were taken at room temperature and 114°K using an apparatus described elsewhere.[6] The room-temperature results on EuO are shown in Fig. 1 and represent the average of nine repetitions of the experiment. For comparison, Fig. 1 also shows room-temperature data on EuS by Mullen and Lawson[2] and on EuSe by Wachter.[3] These curves may be summarized as follows:

The reflectivity spectrum of all three chalcogenides can be described in terms of four principal peaks which we have labeled E_1 through E_4. The peak E_1 shifts to higher energy with increasing anion atomic number (increasing lattice constant), occuring at 1.55, 1.95, and 2.10 eV for EuO, EuS, and EuSe, respectively. On the other hand, E_2 moves to lower energy with the heavier anion, being located at 4.72, 4.2, and 3.9 eV for the oxide, sulfide and selenide. Peaks E_3 and E_4 appear to behave in a fashion similar to E_2.

The reflectivity amplitudes of E_1 seem to decrease while those of E_2 increase with increasing anion atomic number. However, in the case of EuO, the high chemical reactivity may result in surface contamination thus unduly lowering the reflectivity of the E_2 peak.

For EuO, E_1 has been found to have a positive temperature coefficient of $4.7 \pm 0.3 \times 10^{-4}$ eV/°K for temperatures well above its Curie point. This result is in contrast to those from data taken on the low-energy absorption tail of EuO single crystals.[7,8] We point out that temperature measurements on an absorption tail often contain line-narrowing effects in addition to energy shifts. We indeed observed line narrowing of the E_1 peak as well as a paramagnetic red shift with decreasing temperature. It may well be that this narrowing causes the observed blue shift in the absorption data.

Using a least-squares parameter estimation computer program, we have obtained a reasonable

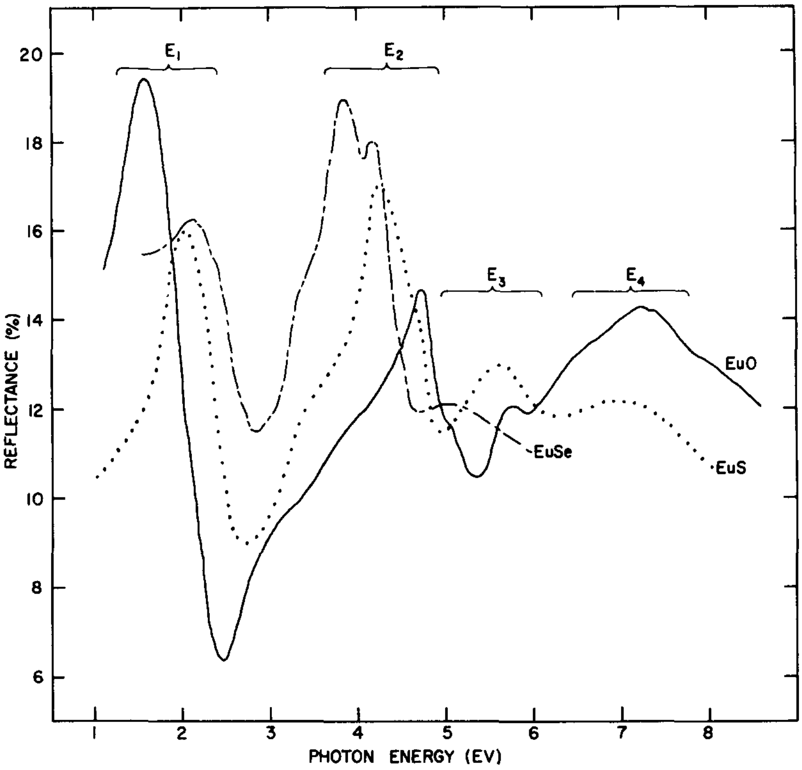

Fig. 1. Room-temperature, near-normal incidence reflectivity of EuO, EuS, and EuSe. The curve for EuS is taken from Ref. 2 and that for EuSe from Ref. 3.

fit of a four Gaussian line dielectric constant model to our EuO data. The results show that the E_1 peak is ϵ_1-dominated ($\epsilon_1 = n^2 - k^2$) which explains why it appears at a lower energy than the corresponding peak in thin film transmission data.[4] The center energy of the Gaussian ϵ_2-peak($\epsilon_2 = 2nk$) for E_1 is 1.78 eV. The absorption coefficient computed from our derived complex dielectric constant yields a peak at 1.95 eV in reasonable agreement with transmission results.

Insofar as one can use a one-electron description for optical excitations in europium chalcogenides, we will discuss our results in terms of the energy-band diagram of Fig. 2. We must remark, however, that a large part of the total energy of a $4f$ electron will derive from correlation effects and it is questionable whether such electrons, and configurations arising therefrom, can be represented in a one-electron energy band picture. The schematic band diagram of Fig. 2 is essentially that of Cho[1] with two modifications. We show the $4f$ level above Γ_{15} in agreement with later calculations by Cho[9] and also with earlier work by Methfessel.[10] In addition, we show Γ_1 below X_3 in view of recent theoretical work by Yanase and Kasuya[11] and also recent photoconductivity measurements.[12] It is interesting to note that the s and d bands of Fig. 2 are quite similar to those derived much earlier by Slater and Koster[13] for general fcc structures by the LCAO method.

On this model, peak E_1 of Fig. 1 is assigned to a $4f \rightarrow X_3$ transition or to an exciton associated with it.[5,10,11] This assignment is consistent with our

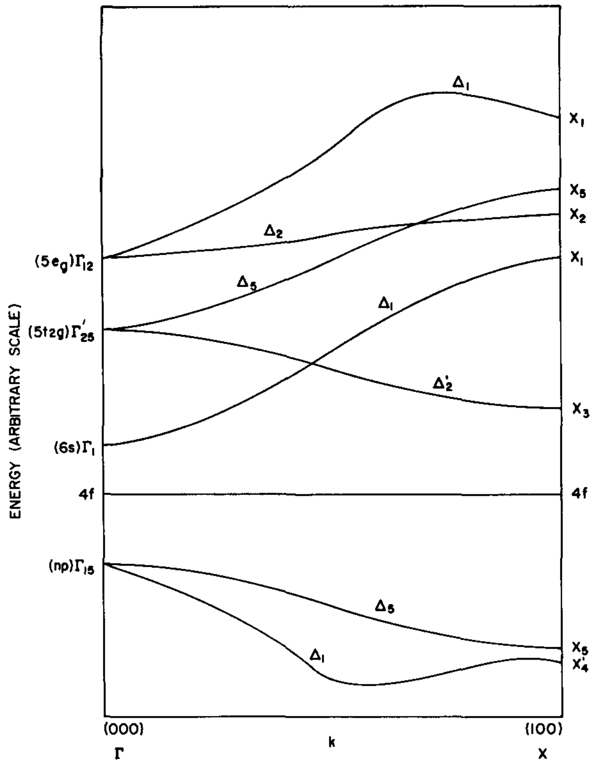

Fig. 2. Schematic one-electron energy band diagram for europium chalcogenides.

observations above, i.e., a decrease in interatomic distance with either decreasing anion atomic number or temperature should lower X_3. This results from an increase in crystal field splitting $(\Gamma_{12} - \Gamma_{25}')$ and increased band broadening due to greater [110]-directed nearest-neighbor europium $5d$–$5d$ overlap.

Several possible assignments exist for the observed high energy peaks E_2, E_3, and E_4. Among these are $\Gamma_{15} \rightarrow \Gamma_1$, $\Gamma_{15} \rightarrow \Gamma_{25}'$, $\Gamma_{15} \rightarrow \Gamma_{12}$ as well as $4f \rightarrow \Gamma_{25}'$ and $4f \rightarrow \Gamma_{12}$. For E_2, $4f \rightarrow \Gamma_{25}'$ is inconsistent with the fact that this peak shifts to higher energies with decreasing lattice parameter. On the other hand, the high absorption coefficient[4] in addition to the correlation in energy between E_2 in EuO, EuS, and EuSe and the first strong transition in the barium chalcogenides BaO, BaS, and BaSe[14] suggest $\Gamma_{15} \rightarrow \Gamma_1$ as a reasonable tentative assignment for E_2. However, $\Gamma_{15} \rightarrow \Gamma_{25}'$ and $4f \rightarrow \Gamma_{12}$ are also strong candidates, and one should not rule out possibilities at other more general points and directions in the Brillouin zone.

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INTERACTION MECHANISMS OF LASER TRANSITIONS IN ARGON AND KRYPTON ION LASER*

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A mechanism is proposed to explain anomalous interaction effects between laser lines in Ar^+ and Kr^+. Radiative transitions connecting the upper level of the directly modulated laser line and the lower level of the cross-modulated line are responsible for the anomalous behavior. This mechanism is supported by the presence or the absence of reciprocity in the anomalous interaction related with the presence or the absence of oscillation on the connecting transition, by the strong "out-of-phase" cross modulation on the connecting transition, and by the lack of upper-level pumping processes suitable for explaining the anomalous interaction.

Interaction between lasering transitions in ion lasers give rise to "normal" competition when the increase in the intensity of one laser line results in a decrease in the intensity of another one. The opposite behavior, referred to as "anomalous," is also observed.[1] Both kinds of interactions can be evidenced with a wavelength selective feedback modulation system such as the one described in Ref. 1, where results on the interactions between argon ion laser transitions are reported, but only the "normal" competition is explained.

Normal competition occurs when two laser transitions have the same upper or lower level or when a thermalization mechanism couples their upper or lower levels.[2,3]

In this letter we describe an interaction mechanism which accounts fully for the observed cases of anomalous competition in argon and krypton ion lasers and we report a set of experimental results supporting our explanation. We have observed that the anomalous behavior of the competition between two laser lines is always associated with the presence of a radiative transition connecting the upper level of the directly modulated laser line with the lower level of the cross-modulated laser line.

For example (see Fig. 1), the anomalous competition between the 4880-Å $(4p\,^2D_{5/2} \rightarrow 4s\,^2P_{3/2})$ and the 4965-Å $(4p\,^2D_{3/2} \rightarrow 4s\,^2P_{1/2})$ laser transitions, oc-

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