Nonequilibrium phonons in insulators and semiconductors

T. I. Galkina

Usp. Fiz. Nauk **156**, 375–377 (October 1988)

Nonequilbrium Phonons in Nonmetallic Crystals, Eds. W. Eisenmenger and A. A. Kaplyanskii, North Holland, Amsterdam; Oxford; New York; Tokyo, 1986. 721 pp. (Modern Problems in Condensed Matter Sciences. V. 16. Gen. Eds. V. M. Agranovich and A. A. Maradudin.)

The traditional ultrasonic methods developed up to the present have for their limiting frequency of elastic oscillations $\sim 10^{10}$ Hz. However the technique of thermal pulses rapidly developing during the last twenty years has made it possible to raise the limit right up to frequencies at the border line of the Brillouin zone, i.e., up to $\lesssim 10^{12}$ Hz. Similar frequencies are attained also in generating nonequilibrium phonons in the case of optical excitation. The methods of detecting such phonons were being developed simultaneously with the methods of generating them; it is now basically possible to speak of the creation of a new field of physics of the condensed state—the spectroscopy of nonequilibrium (acoustic) phonons. The volume under review contains monographic review articles devoted to this subject. They provide the modern concepts regarding the developing field of solid state physics related to the physics of phonons in the terahertz and subterahertz range.

In the first chapter O. Weis examines the problem of the transfer of heat across a solid-solid interface. This is of great importance for operating with the characteristics of "phonon generators," which frequently in the simplest cases are metallic films sputtered on a semiconductor or an insulator and heated either by a current or by a laser beam. The transmission and reflection of phonons at the interface is discussed from the point of view of continuum elasticity theory.

Chapter 2 (H. J. Maris) present the basic ideas of a most beautiful phenomenon in the physics of nonequilibrium phonons—the focusing of phonons; focusing of phonons, or, more accurately, the concentration of the flow of phonons into selected directions, arises as a consequence of the anisotropy of the elastic properties of materials, since the direction of propagation of phonons differs from the direction of their wave vector. Numerical data concerning focusing which are very important for experimenters are provided for cubic, hexagonal and trigonal crystals. The focusing of phonons must necessarily be taken into account in the case of propagation ballistic phonons; but even in studying classical heat conductivity (when the mean free path is considerably smaller than the dimensions of the sample), particularly in the cases when the data on the mean free paths of phonons is unavailable, the knowledgte of the anisotropy of phonon propagation will enable one to determine realistically the optimum heat removal.

In Chap. 3 Y. B. Levinson describes the regimes of phonon propagation—quasiballistic and quasidiffusion—which he introduced together with D. V. Kazakovtsev. In contrast to classical propagation regimes, e.g., ballistic (collisionless) and diffusion, these regimes are characterized by a simultaneous change in the spectral composition of phonons. Both in the USA and in the USSR these concepts have been experimentally confirmed. A theory of nonlocal heat conductivity is developed which solves the problem that has been posed some time ago by Peierls—a formal divergence of heat flux in the case of dominant Rayleight scattering of phonons by impurities.

Chapter 4 (L. J. Challis) describes a broad range of phenomena which have been called by the author the "crossing" effect. It essentially consists of the following. It is well known that the presence in the material of ions or defects with excitation frequencies lying within the limits of the spectrum of the phonons being transmitted will be lead to the scattering of phonons of corresponding frequencies by the centers, i.e., to the increase in the thermal resistance of the sample. If the levels of some center are restructured (for example, by a magnetic field), then when the frequencies of two different excitation coincide an additional change in the thermal resistance of the sample brought about by the effect of the interaction of these excitations ("crossing") will be observed. A measurement of the "crossing" signals enables one to obtain information on the characteristic frequencies of the centers. The high sensitivity of the described experimental techniques is based on the utilization of the differential method of measuring the heat flux with the aid of the modulation method. The limiting resolution of this method is $\sim 5\cdot 10^{-4}$, and this amounts to several Mhz in frequency and makes it possible to resolve the hyperfine structure of the levels.

In Chap. 5 W. E. Bron calls particular attention to the information capability of the "vibronic side-bands" technique (the Stokes and anti-Stokes repetition of the phononless luminescence line). This technique made it possible to obtain, for example, spatial profiles of the phonon distribution for frequencies from 0.5 to 4 THz. Undoubtedly it is of interest to observe the stimulated phonon emission and the direct measurement of the lifetimes of coherent longitudinal optical phonons with the aid of the CARS (coherent anti-Stokes radiation scattering) technique.

Chapter 6, written by F. K. Renk, reports the investigations of the processes of anharmonic decay with the aid of phonon-induced fluorescence. These experiments utilize extensively the technique of restructuring by means of a magnetic field or by uniaxial compression of doublet levels of optically excited impurities. At the present time the detection of phonons by this method has been realized in such materials as CaF_2, SrF_2 and LaF_3.

This chapter gives the only experimental data available

0038-5670/88/100962-03$01.80

in the literature on deviations of the phonon distribution from the Planck distribution and direct measurements of the times of anharmonic decay in the phonon frequency function, and also discusses the possible causes of the deviation of the experimental results from the large number of theoretical hypotheses. The most noteworthy ones are the spectra of nonequilibrium phonons, which vary with time, and this demonstrates in an obvious manner the nature of phonon thermalization as a function of the frequency and the role played by the different regimes of phonon propagation (including also the effect of the crystal surface).

In the following Chap. 7 K. F. Frenk presents the bases for the optical detection of 29 cm^{-1} phonons in ruby with the aid of phonon generation both by metallic heaters and by optical excitation (utilizing also the "exotic" far–IR radiation for direct generation of phonons). The generation of phonons occurs in the transition $2\bar{A} \to \bar{E}$ (of the level of the excited Cr^{+3} ion in ruby split by the crystalline field), while detection is based on observing the inverse transition $\bar{E} \to 2\bar{A}$ by fluorescence. Using this technique spatial profiles of 29 cm^{-1} phonons were obtained and times of anharmonic decay were determined. A discussion is given of the influence of the processes of elastic and inelastic scattering of phonons both for the low-frequency limit, and for the high-frequency limit.

Resonance phenomena accompanying scattering of 29 cm^{-1} phonons by electron states of the Cr^{+3} ions in ruby excited by different methods are discussed in Chap. 8 written by A. A. Kaplyanskii and S. A. Basun. Multiple resonance scattering of phonons (the so-called radiative "imprisonment") occurs when the volume in which they are scattered is much greater than the meanfree path of a resonance quantum. The spatial diffusion of resonance phonon fluorescence enables one to regard multiple resonance scattering of phonons as a new phenomenon, with the kinetic properties of the phonons being analyzed both in the classical and in the quantum approximation. It is shown how the study of resonance imprisonment of phonons in ruby enables one to obtain rich information concerning different mechanisms of scattering of phonons by local electron states in crystals. The phenomenon of phonon imprisonment is of great interest not only for the problem of transport of acoustic phonons in crystals, but also for the general physics problems of resonance interaction of radiation with matter.

In Chap. 9 (L.V. Keldysh and N. N. Sibeldin) material is presented devoted to phenomena associated with the interaction of electron-hole drops (EHD) and excitons with the flux of nonequilibrium acoustic phonons. Nonequilibrium phonons determine in the case of powerful pumping the behavior of EHD—the spatial-temporal evolution of a cloud of EHD in the case of pulsed excitaton, the kinetics of condensation and recombination, the dimensions and concentrations of EHD. On the other hand, information is also obtained concerning the spectrum, propagation and relaxation of phonons.

Unfortunately there is no material in the book concerning the methods of generating and detecting nonequilibrium phonons by using superconducting detectors. However this material may be found in another book published in 1985 by Plenum Press (USA): "The Dynamics of Nonequilibrium Phonons" edited by Prof. W. Bron.

The book under review will certainly be of interest to scientists working in the field of optoelectonics, microelectronics and cryoelectronics.

On the whole the collective monograph "Nonequilibrium Phonons in Nonmetallic Crystals" gives a sufficiently complete idea concerning the present status of research in such a important and timely field of solid-state physics as the physics of phonons of terahertz and subterahertz range. One would welcome the publication of this book in Russian by the publishing house "Nauka," as this would make the book more accessible for the Soviet reader.

Crystal structure of intermetallides

S. E. Sigarev

Usp. Fiz. Nauk. 156, 378 (October 1988)

Landolt-Börnstein. *Numerical Data and Functional Relationships in Science and Technology.* New Series. Eds. K.-H. Hellwege and O. Madelung. Group III: Crystal Structure and Solid State Physics. Vol. 14: Structure Data of Elements and Intermetallic Phases. Subvol. b: Sulfides, Selenides, Tellurides. Pt. 1: Ag–Al–Cd–S...Cu–Te–Yb. Eds. B. Eisenmann and H. Schäfer, Springer-Verlag, Berlin; Heidelberg; New York; Tokyo, 1986. 504 pp.; Pt. 2: Dy–Er–Te...Te–Zr. Eds. B. Eisenmann and H. Schafer, Springer-Verlag, Berlin; Heidelberg; New York, Tokyo, 1986. 492 pp.

The two latest volumes of the well-known reference book are devoted to the atomic structure of intermetallic phases with reference to sulfides, selenides, and tellurides. This publication is a continuation and a supplement of the volume III/6 that was published in this series in 1971, and which included experimental data published up to 1967.

Naturally during the time elapsed since the publication of volume III/6 due to the ever-increasing interest in intermetallides the amount of information on the substances under discussion has significantly increased. As a result of this, the volume III/14 which contains information on more than 4000 substances, is divided into two subvolumes—III/14b1 and III/14b2.

The organization of the reference material in the book is