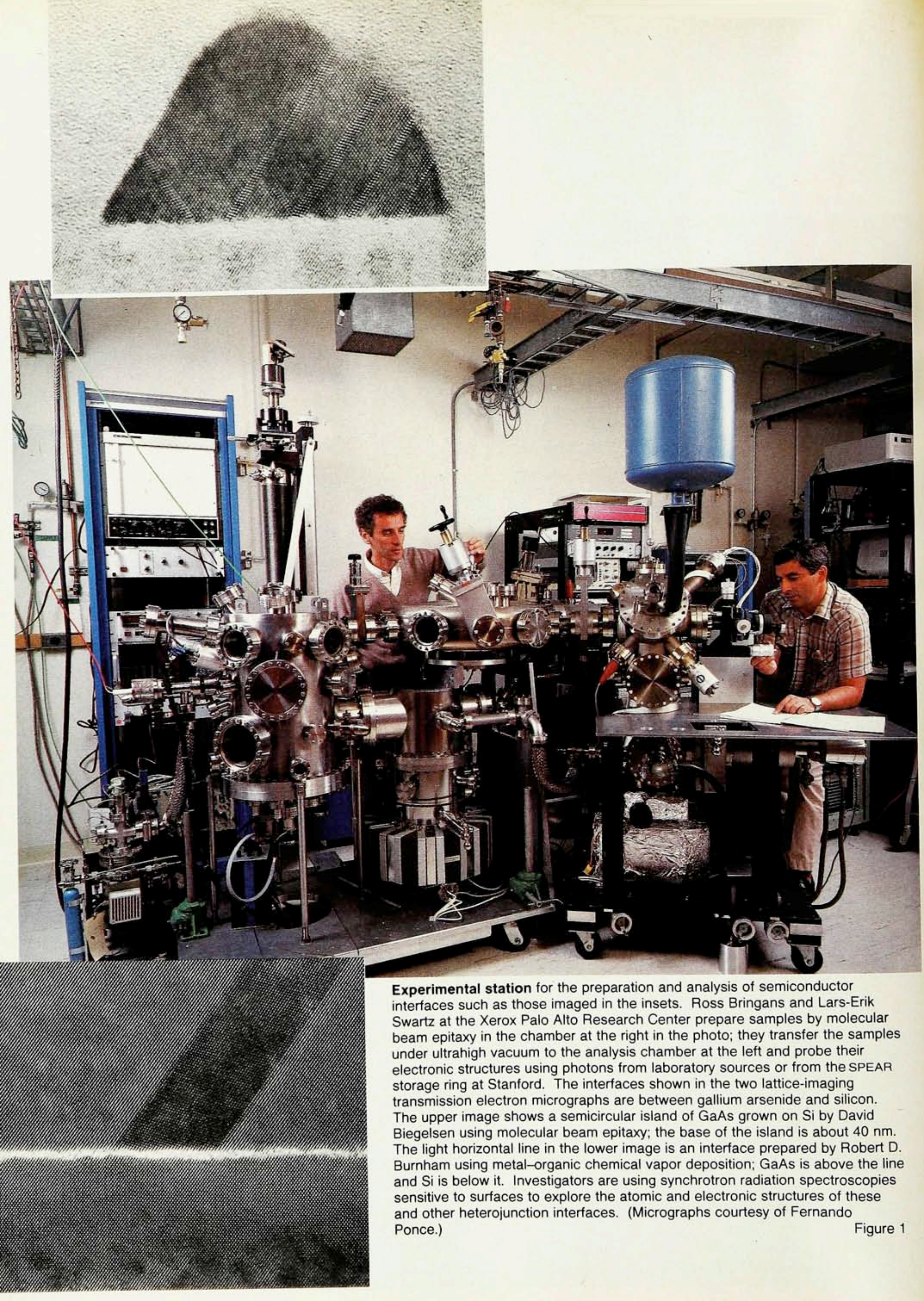

Experimental station for the preparation and analysis of semiconductor interfaces such as those imaged in the insets. Ross Bringans and Lars-Erik Swartz at the Xerox Palo Alto Research Center prepare samples by molecular beam epitaxy in the chamber at the right in the photo; they transfer the samples under ultrahigh vacuum to the analysis chamber at the left and probe their electronic structures using photons from laboratory sources or from the SPEAR storage ring at Stanford. The interfaces shown in the two lattice-imaging transmission electron micrographs are between gallium arsenide and silicon. The upper image shows a semicircular island of GaAs grown on Si by David Biegelsen using molecular beam epitaxy; the base of the island is about 40 nm. The light horizontal line in the lower image is an interface prepared by Robert D. Burnham using metal–organic chemical vapor deposition; GaAs is above the line and Si is below it. Investigators are using synchrotron radiation spectroscopies sensitive to surfaces to explore the atomic and electronic structures of these and other heterojunction interfaces. (Micrographs courtesy of Fernando Ponce.) Figure 1

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Probing semiconductor–semiconductor interfaces

Synchrotron radiation studies are shedding light on the theoretically complex regions between different semiconductors, bringing closer the goal of predicting band structures at the meV accuracies necessary for device applications.

Robert S. Bauer and Giorgio Margaritondo

Almost every aspect of modern life is affected by a practical result of research in condensed matter physics: semiconductor devices. The performance of these solid-state devices is determined largely by the physical properties of the interfaces within them. It is the properties of interfaces in rectifying metal–semiconductor junctions, ohmic contacts, metal–oxide–semiconductor structures and p–n junctions, for example, that determine the performance of such devices as infrared detectors, microwave amplifiers, computer processors and laser diodes, respectively.

The commercial application of interfaces depends on the details of their energy band structures. Hence to exploit interfaces most effectively, one must understand their electronic structures. Homojunctions—the interfaces between differently doped versions of the same semiconducting material—are well understood. The physical properties of the homojunction are determined primarily by the junction electric field, which corresponds to the bending of the valence and conduction bands across the interface. Other important factors in determining the characteristics of homojunctions are bulk properties of the semiconducting material—the mobility of carriers and the width E_g of the forbidden gap, for example.

While the physical properties of homojunctions are well understood and pose no obstacle to their widespread practical application, the same cannot be said for heterojunctions—the interfaces between different semiconducting materials (figure 1). The heterojunction is governed by two sets of semiconductor parameters, corresponding to the two different component materials. In principle this makes the design of heterojunction devices more flexible than that of homojunction devices. The price of this flexibility is the increased complexity of the atomic and electronic structures of the interface, which makes the physical properties of the interface more difficult to understand and exploit. Heterojunctions nevertheless find use in many devices, including high-efficiency solar cells, radiation-resistant integrated circuits and optical sources. Figure 2 illustrates the basic differences between homojunction interfaces and the more complex heterojunction interfaces, which are the focus of this article.

In recent years the availability of synchrotron radiation has enabled experimenters to explore the complex structure of heterojunctions with increasing effectiveness. Synchrotron radiation sources supply intense beams of high-energy photons with tunable wavelengths, enhancing the sensitivity of photoemission spectroscopy in exploring the microscopic properties of all kinds of solid interfaces. Progress in heterojunction interface research due to the widespread application of synchrotron radiation is likely to accelerate as new, high-brightness sources come on line.

Band discontinuities

The edges of the valence and conduction bands are discontinuous across the heterojunction interface. These discontinuities, ΔE_v and ΔE_c, accommodate the difference between the two bandgaps and have no counterpart in homojunctions. The discontinuities have a profound influence on carrier transport properties both along and across the heterojunction. Designing a device around a particular heterojunction requires precise knowledge of the band discontinuities. Alternatively, one can attempt to control the discontinuities to tailor the properties of the heterojunction to particular applications. These approaches are equally important for the design of "superlattices," which are periodic combinations

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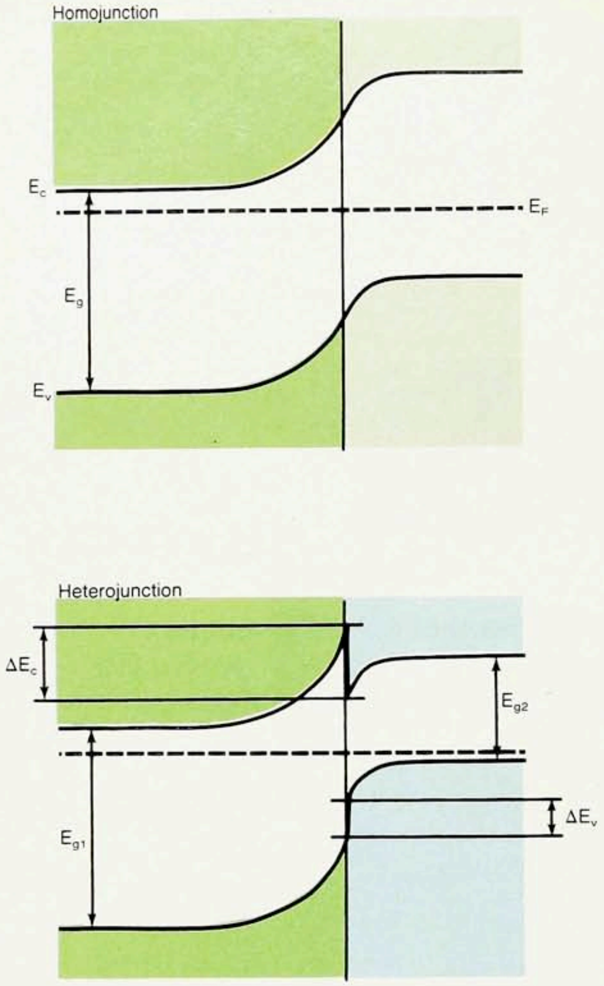


Homojunction and heterojunction band structures. For the p–n homojunction, E_g is the forbidden gap, E_F is the Fermi level and E_v and E_c are the valence and conduction band edges. The heterojunction has two forbidden gaps, E_{g1} and E_{g2}, corresponding to its two component semiconductors. The difference between these two gaps is shared between the valence band discontinuity ΔE_v and the conduction band discontinuity ΔE_c. These discontinuities, not present in homojunctions, determine the performance of heterojunction devices. Figure 2

of heterojunctions.

It is apparent from figure 2 that the change in the size of the bandgap across the interface is equal to the total discontinuity in the valence and conduction bands:

$$E_{g1} - E_{g2} = \Delta E_v + \Delta E_c$$

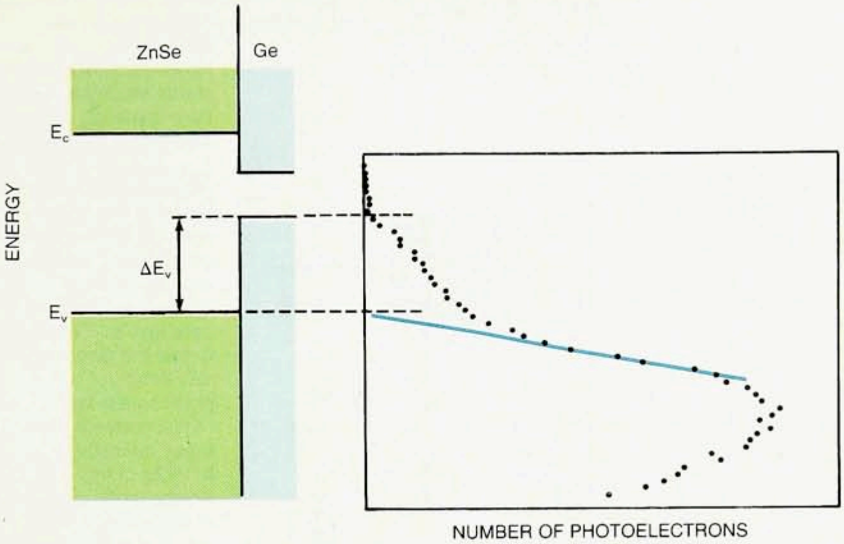
How is the gap difference distributed between the valence band discontinuity and the conduction band discontinuity? Theorists have been studying this deceptively simple problem for over 25 years.[1–10] The problem has not yet been solved either theoretically or experimentally with the milli-electron-volt accuracy suitable for practical applications in optoelectronics and microelectronics.

The difficulty in understanding the band "lineup"—the positions of the valence and conduction band edges on one side of the interface relative to the edges on the other side of the interface—originates in the microscopic nature of the problem. The band discontinuities may depend on both intrinsic and extrinsic characteristics of the two semiconductors. Lattice constants and bandgaps are examples of intrinsic factors, while extrinsic factors include chemical impurities, structural defects, atomic intersection of two materials, interface bonds between heterogeneous species, and lattice distortion at interfaces. All these microscopic factors can contribute to the interface dipole and therefore influence the band lineup.[11] However, such influences as defect dipoles and Fermi-level pinning appear to be less important for heterointerfaces than for other semiconductor interfaces.

Because the band lineup problem deals with the microscopic structure of the interface, it is a natural field for surface-sensitive experimental techniques with high spatial resolution. Photoemission spectroscopy using synchrotron radiation is a leading example of such techniques. The importance of synchrotron radiation to heterojunction research is made clear by the dependence of the escape depth for photoelectrons on their kinetic energy. The escape depth is the distance an electron beam of well-defined energy travels in a solid before its intensity is attenuated by a factor of e. Thus it is a measure of the thickness of the region that is probed by the photoemission technique.

One can control the kinetic energy of the photoelectron by modifying the energy of the photon. Because the escape depth exhibits a minimum of less than 1 nm at 50–150 eV, this is the range at which the surface sensitivity of photoemission is greatest and therefore best for semiconductor interface research. Kinetic energies of 50–150 eV correspond to photon energies of 55–350 eV for the valence band and first-shell core electrons of most semiconductor heterojunction interfaces. Such photon energies are available only from synchrotron radiation sources. The widespread use of synchrotron radiation photoemission in heterojunction research has advanced our understanding of band lineups.

Improved methods for preparing atomically abrupt interfaces through molecular beam epitaxy and metal–organic chemical vapor deposition have been another crucial factor in both scientific and technological progress. These advanced techniques yield extremely high quality interfaces. In particular they closely control the microscopic chemical composition and give excellent crystalline structure across the interface. The lattice-imaging transmission electron micrographs in figure 1 show an example: interfaces between gallium arsenide and silicon, prepared through molecular beam epitaxy and metal–organic chemical vapor deposition.



Valence band discontinuity ΔE_v and photoemission spectrum of the ZnSe/Ge interface. The photoemission spectrum was made by directing soft x-ray synchrotron radiation at a thin layer of germanium deposited on cleaved zinc selenide. The resulting photoelectrons come from the valence band. The photoelectron kinetic energy scale has been shifted toward lower values by an amount equal to the photon energy. The colored line points to the valence band edge of the ZnSe substrate; the energy where the data go to zero is the valence band edge of Ge. Figure 3

The excellent quality of such interfaces is an important factor in modern experiments on heterojunctions. Furthermore, the flexibility of the new techniques for preparing interfaces enhances fundamental scientific interest in heterojunctions by making it possible to produce new crystals not present in nature. For example, computer-controlled epitaxial growth can produce multilayers with periodic stacking of different materials. This gives a one-dimensional translational symmetry with periods that can be much larger than those found in a typical crystal. The fundamental and practical properties of heterojunction multilayers open up a new area of condensed matter physics and technology.

Of equal scientific interest are bond-stretched overlayers. These are thin films grown on top of a substrate with substantial lattice mismatch. In general the lattice mismatch is compensated by misfit dislocations. In several cases, however, the overlayer grows free of misfit dislocations through strain accommodation up to a certain critical thickness: The overlayer atoms are in positions that correspond to the substrate lattice, with their chemical bonds stretched with respect to a normal crystal. Thus in the plane parallel to the interface it becomes possible to grow crystals of one compound with the structure of another. Repeated layers of this type are referred to as strained-layer superlattices. (See the article by John C. Bean, PHYSICS TODAY, October, page 36.)

The novel properties of such heterojunction systems and their potential applications are extremely exciting. By combining advanced interface preparation techniques and surface-sensitive synchrotron radiation probes, one can establish a direct link between experimental physics research and device characteristics. The sophistication and complexity of these probes preclude their direct use in the manufacture of components. However, by taking advantage of the unique ability of synchrotron radiation techniques to correlate device characteristics with chemical and physical features we will be able to develop the basis for further technological advances.

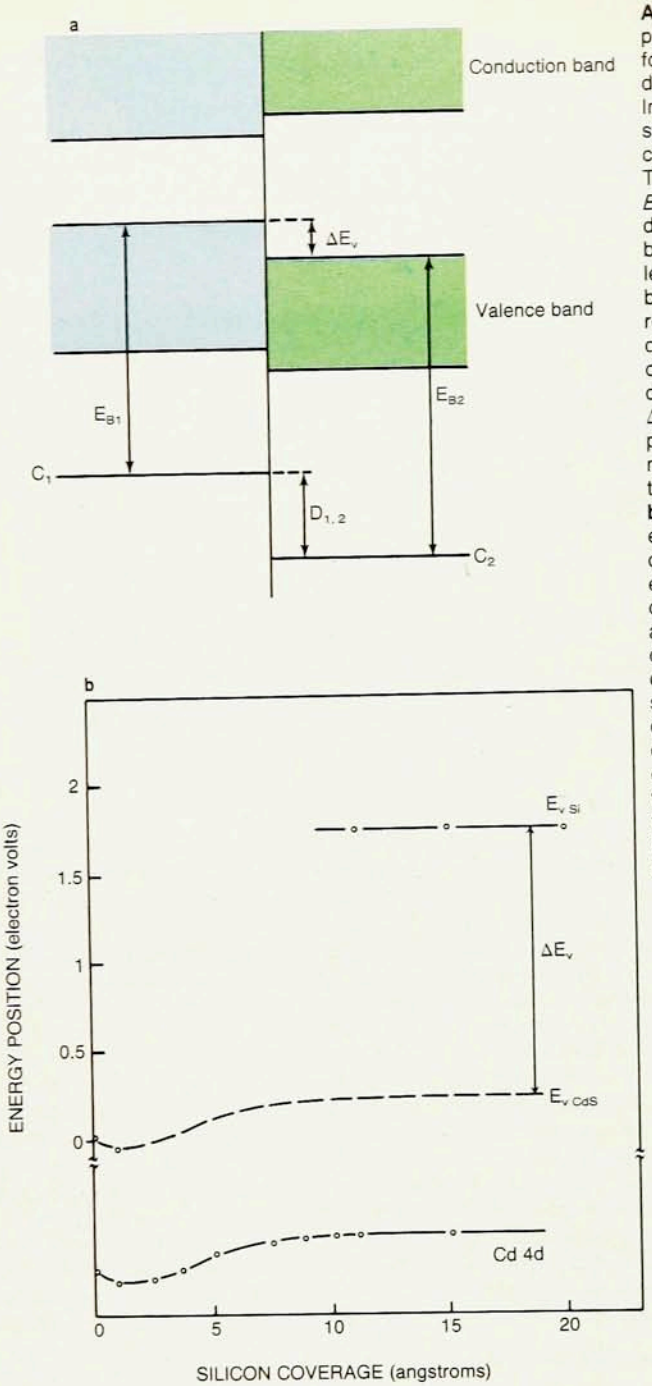
Synchrotron radiation photoemission

Since the mid-1970s, physicists have investigated a variety of heterojunction interfaces using experimental techniques that are sensitive to surfaces. Such research is important because as solid-state devices get smaller and more sophisticated, their performance is increasingly influenced by the local properties of their interfaces. Conventional techniques investigate interfaces only indirectly because they do not probe locally. Direct investigations can be achieved with surface-sensitive techniques such as Auger electron spectroscopy, electron energy loss spectroscopy, low-energy electron diffraction, photoemission spectroscopy and electron microscopy.

Photoemission spectroscopy with synchrotron radiation has emerged as a leading experimental technique for semiconductor interface studies, and for heterojunction research in particular. The spectroscopy of photoelectrons generated by synchrotron radiation has all the advantages of conventional photoemission spectroscopy, with additional flexibility made possible by the photon source. Both conventional photoemission and synchrotron radiation photoemission use the photoelectric effect to get information on the electronic structure of the sample. Conventional photoemission extracts the information by analyzing the energy distribution, and in some cases the direction of emission, of photoelectrons produced by photons of constant energy. Thus only electron parameters are scanned.

With a synchrotron radiation source, one can also control and scan the photon parameters—energy and polarization—and therefore extract more information from the photoelectric process. As we already discussed, one can adjust the photon energy to maximize the surface sensitivity of the technique. Furthermore, photoemission spectra taken with different photon energies can provide a layer-by-layer picture of the chemical and electronic structures of the interface.

The feasibility of using synchrotron radiation photoemission to study heterojunction interfaces was demonstrated for the first time in 1977 by Bauer and

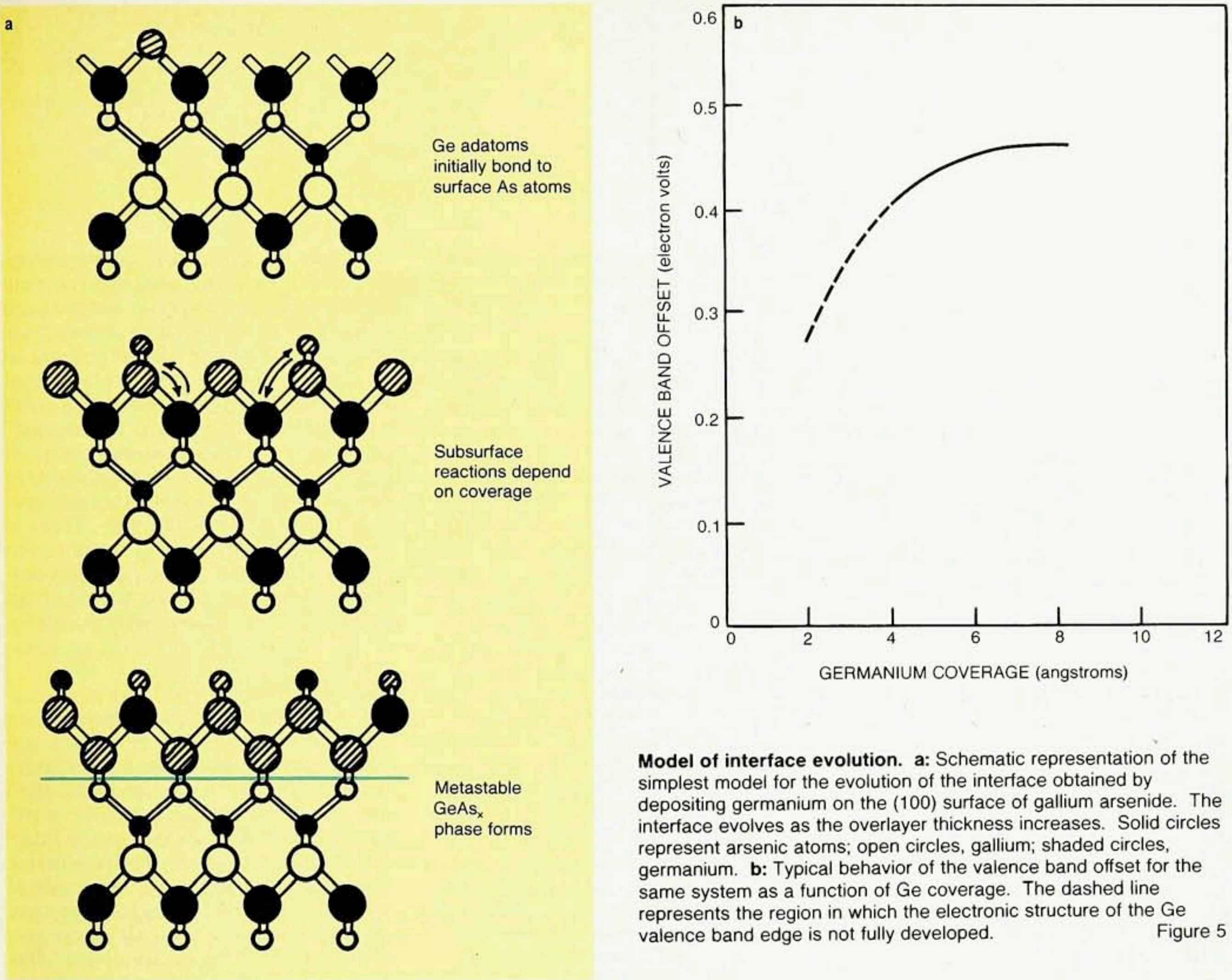


Alternative photoemission method for measuring the discontinuity ΔE_v. **a:** Interface between two semiconductors with core levels C_1 and C_2. The labels E_{B1} and E_{B2} represent the distances in energy between the core levels and the valence band edges, and $D_{1,2}$ represents the distance between the core levels. One can derive the discontinuity ΔE_v from photoemission measurements of these quantities. **b:** Plots of the experimental positions of the valence band edges and the cadmium 4d core level as a function of silicon coverage on a cadmium sulfide substrate. The discontinuity ΔE_v derived from these data agrees with the value derived directly from the double edge in the valence band spectrum. Figure 4

his collaborators at Xerox Corporation in Palo Alto, California,[12] and by Paolo Perfetti and his coworkers at Berkeley and Frascati.[13] Physicists have since performed[14] many experiments with this technique. Photoemission gives a direct measure of the electronic structure of a heterojunction interface, including its band discontinuities. Figure 3 illustrates this point. The left side of the figure shows the band diagram of an abrupt heterojunction interface between zinc selenide and germanium. The band bending is negligible over the narrow region pictured in the figure. The right side shows a photoemission spectrum taken with high surface sensitivity on a cleaved ZnSe(110) substrate covered by a thin Ge overlayer. To a first approximation this spectrum reflects the local density of electronic states of the system. Note in particular the characteristic double-edge structure arising from the zinc selenide and germanium valence band edges. This structure directly reflects the valence band discontinuity.

One can use the photoemission spectrum to make a quantitative estimate of the valence band discontinuity ΔE_v. Unfortunately a double-edge structure is resolved in the spectrum only when the valence band discontinuity is at least several hundred meV. Photoemission measurements of core electrons—a less direct method—must be used when the discontinuity is small.[12–14] The distance between the two valence band edges is related to the distance between core levels on each side of the interface, as figure 4a shows. By measuring the energies of corresponding core-level peaks in the photoemission spectra one can obtain estimates of the discontinuity ΔE_v for virtually all interfaces to an accuracy of ± 0.1 eV, independent of band-bending effects.

Figure 4b shows an example of this approach; here the energies of photoemission features of a cleaved cadmium sulfide substrate covered by silicon are plotted as a function of the overlayer thickness. The estimate of the discontinuity ΔE_v given in the figure is the asymptotic distance in energy between the two valence band edges, $E_{v\,CdS}$ and $E_{v\,Si}$. However, the energy of the edge $E_{v\,CdS}$ is not determined directly from the spectra, but is derived from the clean-surface energy corrected for the shift of the cadmium 4d core level. For this interface one can also measure the discontinuity ΔE_v directly from the double edges in the valence band spectra. Both approaches give a valence band discontinuity ΔE_v of 1.55–1.60 eV. This demonstrates the consistency of different synchrotron radiation pho-



Model of interface evolution. a: Schematic representation of the simplest model for the evolution of the interface obtained by depositing germanium on the (100) surface of gallium arsenide. The interface evolves as the overlayer thickness increases. Solid circles represent arsenic atoms; open circles, gallium; shaded circles, germanium. **b:** Typical behavior of the valence band offset for the same system as a function of Ge coverage. The dashed line represents the region in which the electronic structure of the Ge valence band edge is not fully developed. Figure 5

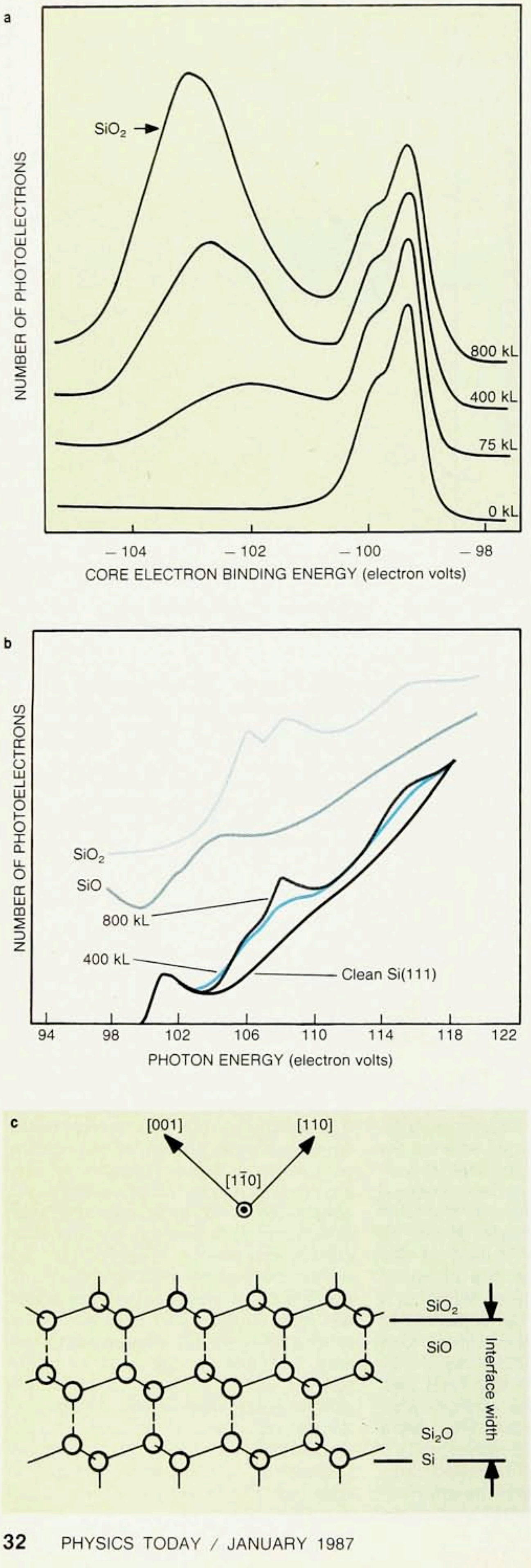
toemission methods in measuring heterojunction band lineups.

There have been two kinds of synchrotron radiation photoemission experiments on heterojunction interfaces. First, investigators have made an extensive effort to measure the discontinuity ΔE_v in a large number of interfaces. Physicists have used the resulting data base to assess the quality of the many theories on band lineups developed over the past 25 years. Second, intensive experiments have examined the effects on the discontinuity ΔE_v of many factors, including crystal orientation, deposition sequence and controlled contamination. This two-sided approach has told us much about the physical origin of heterojunction band discontinuities.

The versatility of soft x-ray photoemission studies using synchrotron radiation has been a crucial factor in this progress. A single set of data can give direct information on the microscopic chemical and electronic structures of an interface. The same data give[15] the band lineup across the interface and the band bending at the surface. Thus a single experiment measures the most important interface properties and explores the physical and chemical factors that determine them.

Use of such an efficient technique is made necessary by the complexity of the process by which interfaces form. Figure 5a shows a simple scheme for the evolution of the microscopic chemical structure of the interface obtained by depositing germanium on the (100) surface of gallium arsenide. Figure 5b shows the parallel evolution of the band lineup. Because the chemical structure influences the band lineup, it is necessary to know the structure in detail at each stage of the process. One determines this chemical structure by carefully analyzing the core-level photoemission spectra of the various chemical components of the interface. Such an analysis is possible, however, only if the energy resolution of the photoemission spectra is high and if the interface signal is not mixed with a stronger signal from the substrate. Both requirements indicate the use of a synchrotron radiation source.

The continuous tunability of synchrotron radiation sources allows one to conduct unconventional core-level photoemission studies that are very helpful in semiconductor interface research. For example, one can measure the dependence on photon energy of the photoelectron signal strength for core electrons of a fixed initial energy or for photoelectrons of a fixed final kinetic energy. In this way one obtains standard spectroscopic "fingerprints" for the interface structure under study. In the case of the interface between silicon and silicon dioxide, for example, correlations between the photoelectron energy distribution taken at constant photon energy (figure 6a) and the photon energy dependence of the photoemission signal at constant photoelectron kinetic energy (figure 6b) can suggest rather detailed models for the structure of the atomic interface (figure 6c).



Analysis of oxidized silicon surface. **a:** Energy distribution of silicon 2p core-level photoelectrons produced by 150-eV synchrotron radiation photons from a Si(111) surface oxidized by exposure to excited oxygen molecules. The exposure level for each curve is shown in kilolangmuirs (1 L is 1 torr sec). **b:** Dependence of the photoemission signal strength on photon energy, measured at a fixed photoelectron kinetic energy of 63 eV (4 eV for the SiO$_2$ curve). Curves for two different exposure levels are shown with data for pure SiO and SiO$_2$. **c:** Model of the interface derived from correlations between the chemical shifts of core levels (**a**) and the spectral signatures of local interactions (**b**). Figure 6

Certainly, important problems remain. For example, synchrotron radiation photoemission measures the band offset for a semiconductor substrate covered by a rather thin overlayer of another semiconductor. One must clarify the relation between this offset and the offset present at "buried" interfaces in real devices. Furthermore, the precision of photoelectron spectroscopy in measuring band discontinuities must be improved. There is no doubt, however, that synchrotron radiation is a unique tool for correlating the physical, chemical and structural characteristics of heterojunctions on an atomic scale.

The band lineup problem

The oldest theoretical approach[1] for determining the lineup of valence and conduction bands across an interface is to use the electron affinity rule and to neglect completely the specific microscopic charge distribution at the interface. One estimates the conduction band discontinuity from the value of the conduction band edges as measured on an absolute energy scale whose zero coincides with the vacuum level. One in turn estimates the energy of each conduction band edge from the electron affinity of the corresponding semiconductor, measured with electron spectroscopy at the surface or estimated through other experiments.

The electron affinity rule is afflicted by many problems other than its neglect of the microscopic electronic structure at the interface. For example, it estimates the absolute position of the conduction band edge—supposedly an intrinsic bulk property of each semiconductor—from the electron affinity—a property of the surface on which it is measured. Old measurements on poorly characterized surfaces were responsible for large differences in the electron affinity data, which made it impossible to test the real limits of the electron affinity rule. Modified versions of this approach tried[1,2] to remove some of its fundamental problems or to identify the specific causes of its limits. Its problems notwithstanding, the rule has been used extensively and for many years in applied heterojunction research. Recently synchrotron radiation measurements provided strong evidence against it.[15]

The approach of considering the band edge positions on an absolute scale while neglecting the specific interface charge distribution is not unique to the electron affinity rule. Other models estimate[3–5] the absolute energies of the band edges through theoretical methods rather than experimental data. Alex Zunger and his collaborators at the Solar Energy Research Institute in Golden, Colorado, and other investigators propose[6] to estimate empirically the absolute energy positions of the band edges from deep impurity levels rather than from electron affinities.

In 1983 Ahmad Katnani and Margaritondo at the University of Wisconsin, Madison, developed[14] an empirical optimization of this class of theories. They used the valence band discontinuities ΔE_v measured by soft x-ray synchrotron radiation photoemission and a least-squares method to estimate the absolute positions of the valence band edges. The table on page 34 contains an updated version of the results. The top of the germanium valence band is arbitrarily used as the zero of the energy scale. The choice of a zero is of course irrelevant to the estimate of the discontinuity ΔE_v, which is made by subtracting the two appropriate terms in the table.

This empirical optimization pushes the above theories to the limit of their accuracy. Unfortunately this limit appears to be very far from that required for device modeling, where one needs an accuracy better than kT at room temperature—that is, an accuracy of a few meV—in predicting the band lineup. No current model is able to reach that kind of accuracy. This sobering conclusion argues against the casual use of band lineup models in technological research.

Another realization is that simple ideas about band lineups may not work, and often cause confusion. Consider for example the technologically important interfaces between GaAs and AlAs or $Al_{1-x}Ga_xAs$. Because valence band states are derived primarily from anions, one could argue that the valence band edges of GaAs and AlAs, compounds that have a common anion, should be close in energy on an absolute scale.[5,11] In fact it was believed for many years that the bandgap difference for the above interfaces was absorbed primarily by the conduction band discontinuity. This seemingly well-established fact was eventually proved to be wrong. It is now clear from photoemission and other experiments that the discontinuities ΔE_v and ΔE_c for the interface between GaAs and AlAs are more nearly equal than was thought. Thus arguments based on the common anion of the two components are misleading in predicting band lineups.

A detailed understanding of the chemical and electrostatic influences on the energy band structure will prepare the way for theoretical prediction of the discontinuity values on the technologically important scale of a few meV. Other methods for analyzing interfaces, such as those based on luminescence and capacitance–voltage measurements, can provide meV precision. However, they will have to be carefully correlated with other techniques if they are to uncover both chemical and physical properties. Synchrotron radiation photoemission simultaneously probes such a broad range of interface properties.

Interface charge distribution

How can we predict the band lineup with an accuracy suitable for technological application? Ideally we would calculate in detail the electronic structures of "realistic" interfaces and obtain the band discontinuities as byproducts. Self-consistent pseudopotential methods have made great progress[7] toward this goal. The detailed description of a real interface, however, is beyond the present—and perhaps future—capabilities of solid-state theory.

The charge distributions at different interfaces may have enough common characteristics to be treatable, at least in first approximation, with a generalized model. Several theorists have taken this approach, most notably Jerry Tersoff at IBM[8] and Fernando Flores and his collaborators at the University of Madrid, Spain.[9] Their approaches belong to a general class of semiconductor interface theories inspired by Volker Heine's concept of electron wavefunctions tailing from the metal into the semiconductor gap in a Schottky diode. Although several theorists have criticized[10] this approach, Tersoff achieved[8] reasonable accuracy in using it to predict valence band discontinuities. The accuracy, however, is still far from that required for technology. Quite interestingly, Tersoff predicts a direct correlation between Schottky barriers and heterojunction band discontinuities. Several experimenters are using synchrotron radiation and other probes to test this prediction, and they have reported somewhat conflicting results.

The failure of current theories to predict band lineups with the accuracy required for technological application emphasizes the need for further theoretical work. Realistically speaking, however, one cannot expect theorists to handle all the factors that could *a priori* influence the band lineup. Experimenters must therefore explore these factors and assess their importance empirically by producing complete and detailed experimental characterizations of the geometric, chemical and electronic structures of interfaces. Because such characterizations are time consuming they can be done for only a small number of "prototypical" interfaces.

Even before we complete the picture of interface structure, the challenging research involved will produce valuable results by identifying at least some of the most important factors affecting the band lineup. We can exploit these factors to control the band lineup and to adjust the discontinuities to fit the needs of specific applications. This capability opens up an entirely new branch of device engineering.

Federico Capasso and his coworkers at AT&T Bell Laboratories succeeded[16] in modifying band lineups by controlling the doping in the interface region. Experiments at Xerox, at the Jet Propulsion Laboratory, at the Frascati National Laboratory in Italy and at the University of Wisconsin, Madison, have produced[17] very large changes in band lineups by controlled contamination of interfaces. Contamination of an Si/SiO_2 interface with approximately a monolayer of hydrogen, for example, changes the valence band discontinuity by up to 0.5 eV. Such process-dependent variations suggest that for some interfaces we may be able to treat interface barriers as adjustable param-

Energies of valence band edges

Semiconductor	E_v (eV)
Ge	0.00
Si	−0.16
α-Sn	0.22
AlAs	−0.78
AlSb	−0.61
GaAs	−0.35
GaP	−0.89
GaSb	−0.21
InAs	−0.28
InP	−0.69
InSb	−0.09
CdS	−1.74
CdSe	−1.33
CdTe	−0.88
ZnSe	−1.40
ZnTe	−1.00
PbTe	−0.35
HgTe	−0.75
CuBr	−0.87
GaSe	−0.95
$CuInSe_2$	−0.33
$CuGaSe_2$	−0.62
$ZnSnP_2$	−0.48

Positions of the band edges are given relative to the valence band edge of germanium. The difference between two terms gives a first-order estimate of the discontinuity ΔE_v.

eters. For other lattice-matched systems of technological interest even drastic chemical and structural modifications may not provide effective variability.[18] These important issues motivate fundamental research in the field.

Future directions

The major trend in heterojunction research is to go beyond theories that neglect the complex microscopic distribution of charge at the interface and to reach technologically useful accuracies both in theory and in experiment. Another important trend is the study of artificial microstructures such as periodic multilayers and bond-stretched overlayers, novel systems that extend the boundaries of solid-state physics. The exploration of the fundamental properties of these systems for both scientific and technological reasons promises exciting theoretical and experimental work. Synchrotron radiation photoemission studies of heterojunction interfaces will be an important component of this expanding area of research.

Advances in synchrotron radiation instrumentation will play a major role in the future of heterojunction research. New sources such as the Advanced Light Source at Berkeley, the low-emittance ring at Trieste and the 6–7-GeV rings at Argonne and Grenoble will have unprecedented brilliance. Technical improvements in optical components such as x-ray mirrors, detectors and monochromators will enable experimenters to exploit fully the enhanced brightness. This will make it possible to reach new performance limits in photoemission spectroscopy.

Core-level spectroscopy with ultrahigh energy resolution, for example, will reveal in microscopic detail the chemical structures of heterojunction interfaces. Investigators will exploit the enhanced brilliance of sources to do synchrotron radiation experiments with high lateral resolution. Together with advanced microscopies such as scanning tunneling electron microscopy, the new synchrotron radiation technologies will allow us to stop simulating interfaces with their two-dimensional space averages and to start exploring interfaces as, in many cases, they really are: laterally inhomogeneous.

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Herman Winick was guest editor for the PHYSICS TODAY series of articles on synchrotron radiation.

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