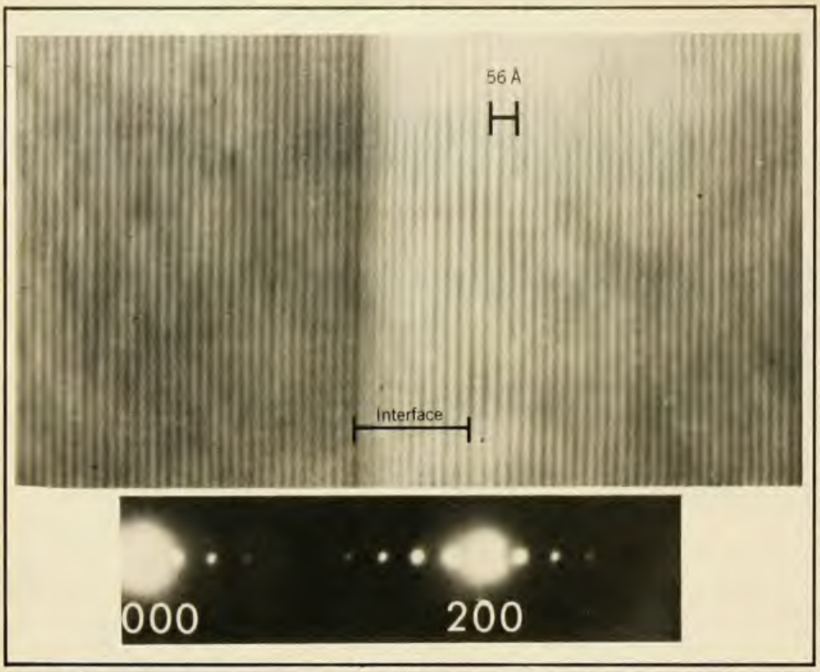

Bright-field transmission electron micrograph of the superlattice grown by molecular-beam epitaxy. The films to the left and right of the interface correspond respectively to a sample region with (8.04 ± 0.38 GaAs−1.5 ± 0.14 AlAs) and a sample region with (6.13 ± 0.29 GaAs−3.37 ± 0.41 AlAs). The lower photograph is a transmission electron-diffraction pattern of the second sample region. The direct beam and the two adjacent satellites are used to form the image above.

TEM analysis showed alternate monolayer composition modulation, it did not show that the structure is perfect. For example, one layer could be interdiffused with another. Another source of imperfection is that the surface with which the Bell team begins is not perfectly flat and so must have atomic steps. Still another imperfection is from formation of crystal-growth islands. To study these imperfections, the experimenters are studying the intensities and widths of superlattice diffraction lines. The coherence length or size of the perfect region will determine the width of the superlattice reflection, analogously to a particle-size effect. The group has found that at substrate temperatures higher than 875 K, they could not obtain good monolayers.

Another check on monolayer formation done by the Bell group is to operate the electron microscope in an image mode, using diffraction contrast. Images are constructed from a direct, undiffracted beam and the beam diffracted by the superlattice so as to form a phase-contrast image. Although the group has been unable to obtain an image of a $(GaAs)_1(AlAs)_1$ composition, they have obtained images for $(GaAs)_2(AlAs)_2$, although the sample was not very photogenic. Images for $(GaAs)_8(AlAs)_1$ and $(GaAs)_6(AlAs)_3$ exhibit very regular and ordered structures of the type shown in the figure.

Evaluation. Early work on superlattices was done by Jesse DuMond and J. P. Youtz at Cal Tech in 1940. Later John Hilliard and his students at Northwestern University and D. de Fontaine and his students at UCLA alternately evaporated noble metals, creating superlattices with a ⟨111⟩ texture and periods as low as three monolayers (7 Å) for the purpose of studying diffusion, Gossard told us.

The IBM group, headed by Leo Esaki, has done pioneering work on superlattices created by molecular beam epitaxy of gallium arsenide and aluminum arsenide. For example, in November, L. L. Chang of IBM reviewed at the Materials Research Society meeting in Cambridge, Mass. the group's recent results of x-ray characterization, transport properties and a resonant Raman scattering experiment.[2] The thinnest sample they have reported is 15 Å thick or five monolayers.

Esaki feels that the new Bell work is, indeed, interesting, whereas its significance, in view of materials science and application, remains to be seen. Although on the average, the Bell sample acts like a monolayer, he said it is likely that some portions consist of two layers and some, none, because of no "natural" long-range order. If one makes thicker layers, such errors should be correspondingly less significant. The seriousness of these unavoidable faults is yet to be assessed, Esaki feels.

Gossard, on the other hand, feels that the Bell technique should allow controlled studies of the effects of atomic structure on electronic structure, the study of diffusion on an atomic scale and the study of the MBE crystal-growth process. Furthermore, the group says, one should be able to tailor-make materials with specific, built-in electronic and optical properties. The layered material, instead of being cubic, has become tetragonal; this change allows one to program optical anisotropy into the material. Raymond Dingle (Bell Labs) observed that photoluminescence from the samples is polarized while Jan van der Ziel (Bell Labs) found from other optical measurements that the band gaps are wider in monolayers than in random alloys of the same material.

Gossard says that in principle the method should work with other materials so that one could concoct compositions that would not otherwise be attainable. He thinks that these new materials should be considered chemical compounds because of the proximity of the inequivalent constituent layers. The Bell team had chosen gallium arsenide and aluminum arsenide because their lattice constants are almost the same. If the match of lattice constants were poorer, Gossard feels that problems might arise. —GBL

References

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Massachusetts dish for radio astronomy at 1 mm

A new millimeter-wave radio telescope was recently dedicated at the Five College Radio Astronomy Observatory, 12 miles from Amherst, Mass. The 45-foot diameter dish will be used primarily to study molecular clouds in our galaxy. The instrument is expected to have the highest resolution at 1 mm wavelength of any radio telescope in the world.

Many large radio telescopes operate at centimeter wavelength. The three largest dishes are the 300-foot dish of the National Radio Astronomy Observatory, Green Bank, W. Va., the 1000-foot telescope of the National Astronomy and Ionosphere Center, Arecibo, Puerto Rico and the 100-meter dish in Bonn, West Germany. The largest arrays are at Cambridge, England, Westerbork, Holland and the Very Large Array now under construction in New Mexico.

However, for millimeter wavelengths, the telescopes are limited in collecting area, sensitivity and availability. Interest in the field has grown since the discovery eight years ago of ammonia and water vapor in galactic dust clouds. Many of the molecules subsequently discovered have transitions at 1–3 mm.

The Massachusetts millimeter-wave telescope is an aluminum paraboloid with diameter of 45 feet, consisting of 72 individual reflector panels, fastened to a back structure by 500 individual mounting points. The back structure is a network of large box girders, similar to an airplane wing. The dish is covered by a 68-foot-diameter radome.

The device is expected to distort under gravity by no more than 0.1–0.15 mm when the dish is tilted from 20 to 80 deg elevation. The error in individual surface panels is only one third as large, Director G. Richard Huguenin told us. Because most of the energy is reflected from the central portion of the surface, the weighted average error is expected to be 0.07–0.08 mm. At present, the Observatory is still making final adjustments of the 500 points. If all goes well, Huguenin said, the telescope will have an angular resolution at short wavelength of about 30 arcseconds. At 1 mm, resolution is expected to be 25 arcseconds.

Telescope design and fabrication was done by Electronic Space Systems Co. in Concord, Mass. Assembly was done by the Observatory. The Observatory is developing traveling-wave masers for operation at 13–2.6 mm. When fully operational, the receivers are expected to have very low noise, with a temperature of 80–100 K. The actual system temperature is limited by the atmosphere.

A major part of current millimeter-wave work is done with the NRAO 36-foot-diameter telescope at Kitt Peak, whose surface accuracy is 0.14 mm. Its best noise figure is 190 K at 85 GHz. The telescope is used at 1-mm wavelengths and longer.

The Onsala Space Observatory of Chalmers University, near Gothenburg, Sweden, has a 66-foot dish with a surface accuracy expected to be 0.25–0.30 mm. Their instrument was also built by Electronic Space Systems. The dish will cover 3-mm wavelengths and longer and will perhaps work down to 2 mm. Taking the ratio of the diameter to the surface precision as a criterion for resolution, Huguenin says the Massachusetts resolution will be slightly better than the Swedish resolution.

Other millimeter-wave telescopes, all smaller, include one at the University of Texas at Ft. Davis, the Aerospace Corp. in El Segundo, Calif., the University of California at Berkeley, and MIT. In addition, optical telescopes such as the 200-inch at Mount Palomar are occasionally used to observe at 1 mm.

The Massachusetts dish will be used primarily to study molecular clouds within our galaxy, observing the various molecular species and their distribution within the galaxy, thus providing clues as to how stars are formed. In addition, it will be used to study the solar system, pulsars and quasars. To go beyond our own galaxy, however, a more sensitive receiver will be required.

The five colleges making up the Five College Radio Astronomy Observatory are the University of Massachusetts, Amherst College, Hampshire College, Mount Holyoke College and Smith College. Over the past five years the Observatory has done pioneering studies of pulsars with its novel meter-wavelength array of spherical telescopes. —GBL

Millimeter-wave radio telescope at Five College Observatory. Photograph shows the box-beam back structure, pick-up arms and pedestal.

Los Alamos meson factory

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(once the machine had shown it could operate at these intensities).

The major problems that were corrected include: adjusting the length of the tanks in one region, replacing the bellows in one element of the support structure for the drift tubes, and improving the alignment. Once the shutdown was completed, the machine was brought up to 100 microamps in August 1976, and now routinely operates at that intensity. Rosen feels that the machine "is solid up to 200 microamps," which is the highest intensity achieved so far.

During fiscal year 1978, Rosen expects to move to 300 microamps, stay at that intensity for a while, and then in FY 1979–FY 1980 move to 700–1000 microamps. LAMPF's closest competitors at the moment are SIN in Villigen, Switzerland, which is a 650-MeV machine now operating at 20–40 microamps (and expected to reach 100 microamps) and TRIUMF in Vancouver, B.C., a 520-MeV machine that is now operating at 10 microamps (and expected to reach 100 microamps by December 1977).

When LAMPF reaches 300 microamps, Rosen anticipates that the problems encountered will probably be in the target cells, in maintaining and repairing systems exposed to primary beams.

Physics experiments. Two major nuclear spectrometer facilities are being readied for LAMPF. The High Resolution Proton Spectrometer (HRS) has achieved better than 100-kV resolution at 800 MeV, with 30–40-kV resolution anticipated. The angular resolution is now 2 milliradians, with 1 milliradian expected for both normal and polarized protons. The spectrometer occupies a dome-shaped room whose 45-foot radius suggests a cathedral dome. A comparable large spectrometer is operating at Saclay. The second device, the Energetic Pion Channel and Spectrometer (EPICS) is partly assembled. The channel is already installed, and riggers recently began installing magnets in their frames. By May experimenters hope to have a pion beam in the spectrometer. EPICS is expected to have a 100-kV resolution for 200-MeV pions and an angular resolution of about 10 milliradians. SIN already has been running a competing spectrometer called SUSI, but EPICS is expected to have better resolution and counting rate.

LAMPF is very much a user-oriented laboratory. Since it began operation, experimenters from more than 128 institutions have worked there.

Darragh Nagle, who heads the LAMPF experimental program, discussed some of the interesting physics experiments going on. Melvin Leon (Los Alamos) has recently predicted the existence of a nuclear resonance effect in pi-mesic atoms. Experiments by Leon, James Bradbury and others have measured the effect in pi-mesic cadmium, samarium and palladium atoms. Besides demonstrating the effect, Leon has shown that the results imply that the zero-energy interaction between pions and the nucleus in the p-wave state crosses through zero and changes sign as the atomic number is increased. Earlier, Torlief and Magda Ericson and Max Krell (CERN) had predicted that the pion–nucleus potential would change sign in this way. Further calculations on the nuclear resonance effect in pionic and kaonic atoms are being done by Leon and by workers at Lawrence Livermore Laboratory. Experiments at the Rutherford High Energy Laboratory with kaonic molybdenum and tin also bear out Leon's calculations.

A collaboration among Virginia Polytechnic Institute, Oak Ridge, Tel Aviv University, University of South Carolina and Los Alamos, led by Barry Preedom (University of South Carolina) and Robert Burman (Los Alamos) has done precise angular distributions for 50-MeV positive pion elastic scattering from C^{12}, O^{16}, Ca^{40}, Zr^{90} and Pb^{208}. The data show that an s- and p-wave interference minimum occurs at 65 deg and also show typical nuclear diffraction minima beginning