a field effect transistor with a 0.1 µm gate. The inability of the electrons to be scattered by phonons when dealing with picosecond time scales makes the electrons travel faster — ballistic regime — and can give most impressive maximum operating frequencies, perhaps beyond 100 GHz.

In looking to the new future of submicron devices, material growth particularly in the compound semiconductors, will play a key role. This topic was reviewed by R.W. Brander and M.M. Faktor of the British Telecommunications Research Laboratories. Brander clearly came down, in the presentation, on the side of expecting molecular beam epitaxy to give the best technique for controlled and selected material growth, at least in the future. The problems of throughput that may trouble mass production were not emphasised by Brander, but were of concern to P.J. Daniel (Philips Research Laboratories, Redhill) in his careful comparison of photo-lithography and electron-beam lithography.

While conceding that the electron beam has clear advantages over photo-lithography in the diffraction limitations, in spite of back scattering of electrons blurring the edges, Daniel believed that the problems of speed of writing for raster or vector scanned e-beam machines would remain. If true, this could have serious consequences for the commercial exploitation of the new physics of sub-micron devices where e-beams may be essential rather than as at present, used to help in discretionary wiring of VLSI.

Indeed the practical difficulties of reducing dimensional tolerances to increase packing densities while maintaining yield in VLSI production processes, may have accounted in part, for the greater interest in vertical integration which appeared in papers time and again. For example, J. Lohstroh (Philips Research Laboratories, Eindhoven) in his review paper indicated he had found it was helping the commercial exploitation of the new physics of sub-micron devices where e-beams may be essential rather than as at present, used to help in discretionary wiring of VLSI.

The Vth European Conference on Atomic and Molecular Physics of Ionized Gases, ESCAMPIG was held in Dubrovnik 1-3 September. This conference is now well established and the organizers, R. Deloche and P.K. Lanev, chose to include several new topics related to the same central theme. This year, for the first time the collisional properties of Rydberg states (F. Gounard) and laser induced inelastic collisions (C. Manus) were presented.

Due to their large size and the weak binding of the outer electron, Rydberg atoms are very sensitive to external perturbation. Gounard gave a very enlightening survey of the collisional properties of these very high atomic excited states, underlining the importance of their role in astrophysics and in laser isotope separation.

Currently the most widely studied process is the total collisional de-excitation (quenching) of a well-defined Rydberg level. Two-step selective excitation of alkaline states, for example, is reached by pulsed dye lasers. Large depopulation cross sections are generally observed \(10^{-13} - 10^{-12}\ \text{cm}^2\). The most interesting behaviour is exhibited by the \(n\) dependence. At rather small values of \(n\), the cross section increases with \(n\), reaches a maximum, then decreases for still higher \(n\) values. It was also shown that the position of the maximum shifts to higher \(n\) values when the mass of the perturber increases. These findings of the Saclay and S.R.I. groups seem to emphasize the dominant role of the electron perturber interaction, although in other situations the influence of the ion core may be more important.

Due to the importance of the subject, this talk was followed by a workshop opened by Deloche, who presented a general account of the various reactions that involve Rydberg states, such as the ionizing processes observed by R.F. Stebbings and A.N. Klutcharev. Deloche also discussed the present situation of the theoretical models and their ability to describe the experimental findings.

The growing importance of laser isotope separation has been very often emphasized. N.V. Karlov presented a very clear survey of the basis and possibilities of such a field. For a great number of atoms, an enrichment of a factor of 100 or even higher has already been obtained. A selective first step laser excitation carries the
Laser Doppler Anemometry

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In the past few years, laser applications of increasing complexity and sophistication have begun to make their way from research to development laboratories and from there into engineering practice, industrial production and marketing. Laser Doppler anemometry is a case in point. In what follows, basic principles, the state of the art and some typical applications will be reviewed. Apologies are made to laser Doppler specialists for what may seem to be a disregard for many of their ingenious schemes and inventions, but interested readers may go more deeply into the subject by consulting references 1, 2 and 3.

The Beginning: Optical Heterodyning

During the development of the first gas lasers, beats between adjacent longitudinal modes were observed. For an L = 1 m long laser, for example, the beat frequency is c/2L = 150 MHz, and it is due to laser modes which differ by 1 in the number of half wavelengths in the standing wave pattern between mirrors. This suggested that with laser beams of adequate spectral purity and wavefronts sufficiently parallel to one another, differences between optical frequencies could be obtained much like intermediate frequencies are obtained by heterodyning radio frequencies. Further exploration of this possibility led to the evolution of heterodyne spectroscopy. Laser light impinges on a sample from which Stokes or anti-Stokes shifted light is scattered through Rayleigh, Brillouin, or Raman effect. Superposition of scattered light with part of the original laser light on a photodetector results in an electrical signal at the difference frequency. H. Z. Cummins, one of the originators of heterodyne spectroscopy, also initiated laser Doppler anemometry. In 1964, he and his coworkers directed a laser beam at particles that were being carried along by a laminar fluid flow. Owing to the particle velocity, the scattered light frequency was Doppler shifted. Superposing the scattered light with part of the original laser beam on a photodetector, they observed Doppler frequency shifts in the kHz range. They moved the spot from which scattered light was collected relative to the flow geometry and, in this way, were able to trace out the parabolic Poiseuille velocity profile, characteristic of laminar flow in round tubing.

The heterodyne method used in laser velocimetry, in the jargon of the field, is called the reference beam method. In association with modern optical and electronic equipment, it is popular for a number of applications, but it suffers the drawback of low sensitivity. For heterodyne detection, scattered light and the original beam should have coplanar wavefronts over the area of the photodetector. That can be accomplished only for a small detector area or, equivalently, for small acceptance aperture.

Other methods of laser velocimetry do not depend on optical heterodyning directly. Their modus operandi may be discussed on the basis of seemingly different, yet fundamentally equivalent principles.

Basic Principle: Time-of-Flight Measurement

In any kind of velocimetry, a distance is marked by element of the apparatus and the time that the object under study takes to travel that distance is measured. Dual focus velocimetry utilizes two focal regions of laser beams as sketched in Fig. 1. Typical dimensions are 10 μm for the beam diameters at their waist and 300 μm for their separation. These beams represent light gates. If a particle (city air or clean water usually contain enough particles for the purpose, otherwise artificial “seeding” may be called for) passes both focal regions in succession it will cause a burst of scattered light in each. Photodetection is arranged to receive light signals from both focal regions in separate channels and the time of passage is equal to the time delay between pulses. The time difference may be obtained for example, by a time-to-voltage converter (originally developed for nuclear physics instrumentation) or by cross correlation. The fast digital electronic correlator used for this purpose will be discussed below.

Fig. 1. — Principle of laser dual focus velocimeter.