(Granatstein, V. L. *et al. Appl. Phys. Lett.* **30**, 384; 1977) used a pulsed-diode electron beam to achieve FEL oscillation at 400 μm in the far-infrared — a wavelength so long that lasing is facilitated by electron-electron plasma interactions that are not useful at short wavelengths.

The successful generation of a 0.65-μm FEL beam in 1983 at the French electron storage ring ACO was the first operation of a FEL oscillator at a wavelength in the visible region (Billardon, M. *et al. Phys. Rev. Lett.* **51**, 1652; 1983). Moreover, it was the first operation of a FEL using the circulating electron beam of a storage ring and the first to achieve laser oscillation with an 'optical klystron' — a modified wiggler design for enhancing the gain of FELs. Both were used because the FEL gain is drastically reduced at short wavelengths — crudely speaking it depends on the number of electrons per optical wavelength along the beam. Therefore to achieve the net gain required for oscillation (of $\sim 2 \times 10^{-4}$ per pass), it was necessary to go to the high current densities and low angular spread characteristic of storage rings and to use the optical klystron configuration: the three central periods were replaced by a three-pole dispersive section, strongly enhancing the optical bunching produced in the first section, thereby giving greater energy exchange (gain) between electrons and radiation field in the second undulator section. Typically, 75 μW average output power was obtained for a 2 kW intracavity peak power, giving 2.4×10^{-5} efficiency with respect to the total synchrotron radiation power. Tunability was shown to be limited only by the cavity mirror coatings, whose average reflectivity was at the technically available limit of 99.965 per cent. Higher ratios of gain to loss are expected from the use of better mirrors and smaller beam transverse dimensions.

More recently a laser oscillation at 11.6 μm in the near-infrared has been achieved by passing the electron beam of the Stanford superconducting linac through a tapered wiggler built at TRW, California (Edighoffer, J. *et al. Phys. Rev. Lett.* **52**, 344; 1984). The tapered wiggler configuration, in which the spacing between successively alternating magnet poles is gradually decreased towards the downstream end of the wiggler as the electron beam gives up energy to the radiation field, is the principle current approach towards the achievement of very-high-power, high-efficiency FELs in the near-infrared. To compensate for the average energy loss of the electrons to the optical wave, the magnetic field is made a function of the wiggler position, hence retaining a constant resonant condition for the output wavelength. The output power was reported as 4 W average or 1.2 MW peak (in a 4 ps micropulse) at 1.57 μm, extracting energy from the electron beam in the tapered wiggler with an efficiency of better than 1.2 per cent.

Last November, the FEL at Los Alamos National Laboratory joined the small group of FELs that have achieved oscillation. During 70 μs pulses, 1 kW average output power was generated, which is reportedly a 100-fold improvement over previous experiments. By adjusting the electron energy the output wavelength was tuned over the range of 9–11 μm — the limits being set by the characteristics of dielectric-coated ZnSe mirrors. The FEL utilized a high-gain low-efficiency uniform wiggler. The efficiency of laser output to electron energy was about 0.25 per cent; small-signal gain was 15–20 per cent per pass.

There are hopes that tapered wiggler lasers will eventually operate with efficiencies closer to 20 per cent. But these high-power devices are probably too disruptive for storage ring beams. Restricted to linacs, they may be limited to infrared applications, though a tapered wiggler lasing in the visible is the goal of the radiofrequency linac development programme of the Math Sciences Northwest and Boeing groups. Clearly, efficiency is a much more important issue for the military and industrial uses of tapered wiggler FELs than it is in the use of visible and ultraviolet FELs, based on storage rings, for research purposes.

In the coming months we can expect a number of other FEL oscillators to become operational. In Britain, the UK FEL is a collaborative programme between Heriot Watt and Glasgow Universities and Daresbury Laboratory, based on the 30–150 MeV linac at the Kelvin Laboratory, Glasgow. The experiment is centred on 10 μm, but a tuning of at least 2–20 μm is being investigated, with extension via harmonics to the visible range of the spectrum. This tunable high-intensity picosecond laser source is intended for research into fundamental properties of solids and molecular genes. A flexible high-gain uniform wiggler system, constructed from permanent magnet blocks, is enabling a thorough study of its operating parameters. A very similar programme is under way at CNEN (Atomic Energy), Frascati, using a 20 MeV microtron source, allowing FEL operation in the range 25–35 μm with a permanent magnet wiggler; at a later stage a new 30 MeV source will allow extension down to 10 μm. Bell Telephone are using a 20 MeV commercial microtron in conjunction with a long helical magnet to give an output tunable from 100 to 400 μm, dedicated to spectroscopic studies. The University of California at Santa Barbara hope to establish a user facility, based on an electrostatic accelerator, for far-infrared condensed matter studies with an average power of several kilowatts. Livermore are preparing to apply an alternative linac technology — the ETA and ATA high-current induction linacs — to the tapered wiggler FEL. Visible and UV storage ring experiments include those at Brookhaven and Frascati, and further extension to the extreme-UV down to 500 Å at Stanford. □

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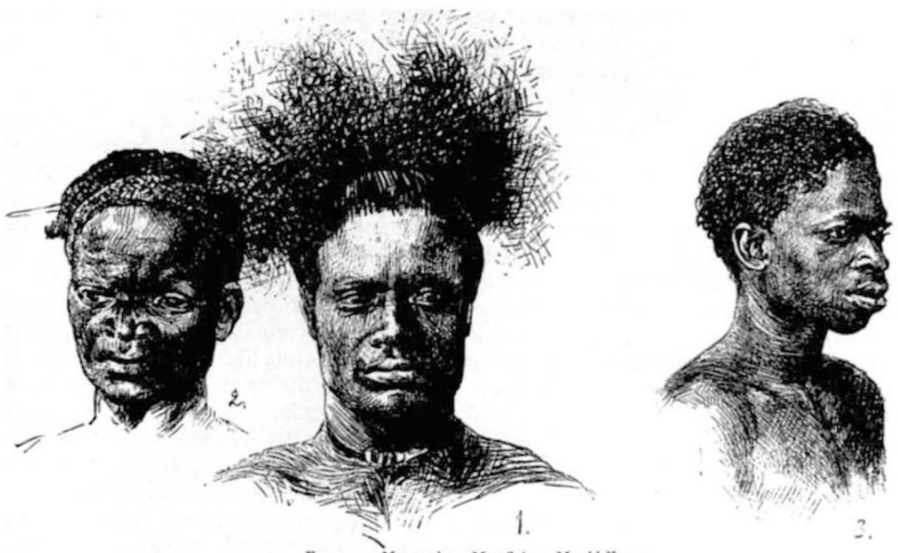

FIG. 3.—1, Mu-yansi; 2, Mu-téké; 3, Mu-shi-Kongo.

100 years ago

The River Congo, from its Mouth to Bólóbó, by H. H. Johnston

ALTHOUGH claiming to be little more than the record of a passing visit paid to the Lower Congo Basin towards the end of the year 1882, this is really a work of permanent interest to the naturalist and ethnologist. The author, a young and ardent student of biology in its widest sense, here conveys his impressions of West African life and scenery in a series of graphic pictures, which owe much of their freshness and vigour to the circumstance that they are always drawn at first hand from nature.

There is a deeply interesting chapter on the "People of the Congo". Here we find the Bantus as a race distinguished by a good observer, not only from the Hottentots, Hamites, and Negroes proper, but even from the surrounding Negroid populations. Further on the Bantus themselves are said to vary considerably in physical appearance, a statement fully borne out by the accompanying typical heads of a Mu-yansi, a Mu-téké, and a Mu-shi-Kongo (see Fig. 3).

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