instead attributed the 3.4 eV peak to recombination of free excitons. The doping of GaN with impurities either gives rise to new bands or enhances the triplet. Grimmeiss reports that the doping of gallium nitride with lithium, sodium, copper, silver, gold, zinc, cadmium, barium, mercury, tellurium, tin and lead gives rise to photoluminescence bands with maxima at twelve different wavelengths in the violet to yellow range; mercury produces a band with a maximum at 2.1 eV (0.59 μm, orange). Doping with beryllium, magnesium, calcium, aluminum, and indium produces no new bands but enhances the ultraviolet emission. Soviet workers have found acceptor levels on doping with zinc, cadmium, and lithium; these levels are located 0.40, 0.69, and 0.95 eV above the top of the valence band.

Gallium nitride has been used in the construction of luminescent MIS (metal–insulator–semiconductor) diodes with a Si_3N_4 insulator film 0.1 μm thick (Pankove and Norris, *loc. cit.*). The luminescence spectra of such diodes include a wide band of 2.1 eV energy (0.59 μm, orange) and an ultraviolet band at 3.28 eV. Green-emitting MIS diodes based on zinc-doped GaN and magnesium-doped GaN have been made in this way: the latter material emitted in the violet part of the spectrum. The efficiency of these structures was 10^{-5}. Diodes emitting yellow light and characterised by an efficiency of 4.10^{-4} were prepared from n–i structures with the high resistivity regions doped with zinc. This is comparable to the efficiency of gallium phosphide green light emitters. In these n–i structures, the light was produced by a pulsed voltage, of, say, 30 V, applied to a metal electrode over the i layer. The light emitted could, of course, be viewed readily through the sapphire substrate, and segmented displays have been made in this fashion. Moreover, it is understood that these devices have operated for several months without degradation in performance. Kesamanly (*loc. cit.*) also reports that GaN will alloy with indium nitride and that the band gap is adjustable thereby.

It thus seems that GaN is on the threshold of becoming a new tool in the hands of the semiconductor physicist. It will be more versatile than other III–V compounds both because the diodes will emit light over the whole of the visible range and because GaN is completely transparent in the visible. It will be of great interest to see what benefits this will bring to our technological repertoire and which country (the United States, United Kingdom, Soviet Union, Germany) leads the way in developing new gadgets—say a white-light laser or solid television display—from this advance.

Dilatancy without fluid flow?

from Peter J. Smith

IT should be quite possible to predict earthquakes on a purely phenomenological basis with little, if any, understanding of the physical process involved. All that would be necessary would be to find a premonitory effect which is common to all earthquakes, or at least to a class of earthquakes large enough to give prediction some practical significance. In recent years, for example, it has been observed that, before some shallow events, the seismic wave velocity ratio V_p/V_s suddenly decreases and then rises again to its normal value just before the shock takes place. This phenomenon may or may not turn out to be a way of predicting shallow earthquakes on a routine basis; but whether it does or not need not depend on any insight into the cause of the velocity changes.

Nevertheless, there is some advantage in having a physical model to explain the observations. For one thing, it tends to inspire confidence; and if there is one thing likely to be required in abundance when it comes to practical prediction, it is confidence. More specifically, an understanding of the mechanisms involved may lead to the discovery of new relationships, and thus bring practical prediction closer. For example, there can be little doubt that the dilatancy model, first proposed by Nur (*Bull. Seismol. Soc. Am.*, **62**, 1217; 1972) and subsequently developed and modified by others, has done almost as much as the observations themselves to produce the new wave of optimism in prediction work. By relating the various premonitory effects such as V_p/V_s changes, resistivity variations and the migration of seismicity to a common mechanism and a common precursor time–earthquake magnitude scale, the dilatancy theory has produced the comfortable feeling that everything is beginning to fit nicely together.

But is the theory correct? Or to put the question in the more limited form that Stuart (*Geophys. Res. Lett.*, **1**, 261; 1974) now puts it: are the current dilatancy models involving fluid flow correct? Insofar as there have been no serious objections to the dilatancy–fluid diffusion mechanism, the question may seem superfluous. But as Stuart points out, the theory apparently defies Occam's razor by introducing fluids without a proven need. Moreover, there are good scientific reasons for questioning the occurrence of fluid diffusion, described by Stuart as the "requirements of ubiquitous finite permeability, existence of pore fluid, and ostensibly great distances involved for large earthquakes".

Stuart's new model has the earthquake occurring within a relatively thin shear zone which has mechanical properties quite different from those of the crustal rocks further away. In the shear zone, the energy applied during deformation is dissipated by creep. In the surrounding crustal rocks, on the other hand, the deformation energy is stored elastically until such time as it is released in an earthquake. Assuming that the two regions are each homogeneous and in welded contact, their stresses at any time will be similar but the strains will differ significantly. To a first approximation the outer rocks will have a linear stress–strain relationship, whereas the shear zone is assumed to have a stress–strain curve possessing a maximum stress.

The crustal rocks in Stuart's model thus have properties comparable to those of the material in conventional dilatancy models; and these rocks are likewise assumed to possess cracks and fractures. The crucial difference is the non-linear behaviour in the thin shear zone. As the stress applied to the combined system increases, dilatancy will occur as the cracks open in the crustal rocks, giving rise to a decrease in V_p/V_s. But as the stress continues to increase, dilatancy in the crustal rocks will reach a maximum and then decrease as the cracks begin to close up again, V_p/V_s will correspondingly increase. The earthquake will occur when V_p/V_s is back to normal, if the energy conditions are favourable. (If the conditions are not so favourable, Stuart's model suggests that rapid creep might occur instead; in other words, the model implies that similar premonitory events herald both earthquakes and accelerated creep.)

It seems, therefore, that the V_p/V_s changes observed in the field may be explained quite well without involving fluid; the inflow of fluid (to raise V_p/V_s) in conventional dilatancy models is replaced in Stuart's model by closing cracks. Fluids may indeed be present, but they are not necessary to the argument. Qualitatively, the two models predict similar precursory variations in V_p/V_s, resistivity, and so on.

But there is at least one difference which should enable the models to be distinguished. In Stuart's model the dilatancy reaches a maximum and decreases to vanishing point before the earthquake as the cracks close. In the diffusion model the dilatancy goes on increasing up to the earthquake. Moreover, because it is diffusion controlled, the dilatancy in the latter case will only decrease slowly after the shock. In time, therefore, it should be possible to test the validity of the two models by geophysical measurement.