came fainter. This indicated that the line originated from a faint galaxy, perhaps a dwarf galaxy—very small, faint objects that abound in the universe. We do not know their exact distribution because they are difficult to observe beyond a certain distance. Another surprise from the GRB on 8 May was that this time the Very Large Array of radio telescopes in New Mexico detected a radio counterpart that also seemed to be variable (*11*). This was the first radio emission detected from a GRB.

What is the theorist's take on all this? Currently favored is an expanding fireball model with all its variants (*12, 13*). This model (see figure) describes the radiation of a fireball that is produced at the site of a GRB by some mechanism (such as merging neutron stars in distant galaxies) in terms of the time scales necessary for the radiation to escape from the originally dense bulge of the hot and expanding plasma. The x-ray data indicate that the plasma cools at a rate inversely proportional to the time interval (t^{-1}) since the GRB; the theory concurs. The optical light curves observed so far are not similar. The February event showed only a decay, whereas the May one exhibited two peaks before it decayed with a t^{-1} relation.

What is the prospect of the field and what is next? In what may be a new era in high-energy astrophysics we must answer questions such as, what is, if any, the correlation between GRB intensity and intensity of emission in other wavelengths? Does the geometry of the emitter change with wavelength? If so, are there GRB counterparts for which the gamma rays were never detected because they were not directed towards us? Is there a "typical" optical light curve of a GRB, as there seems to be a "typical" x-ray one?

After 30 years we find ourselves just starting to unravel the GRB enigma. In addition to the BeppoSAX instruments, the recent, successfully tested rapid scanning of BATSE GRB error regions with NASA's Rossi X-ray Timing Explorer (RXTE) has now also produced x-ray counterparts. In a few years approved and proposed missions such as HETE and BASIS may increase the suite of instruments available to find GRB counterparts. And as our counterpart sample increases, we may be able to establish the GRB origin and probe to deeper cosmological distances to the early stages of the universe.

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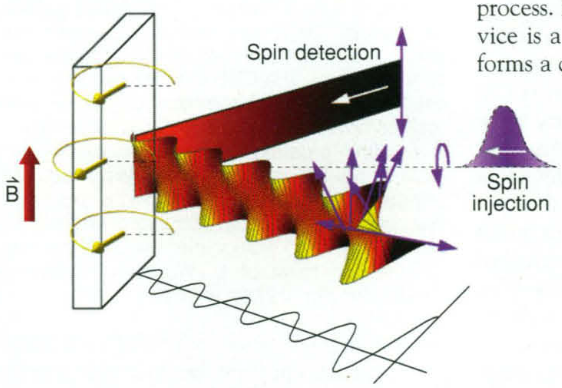
SEMICONDUCTOR DEVICES

Closer to Coherence Control

Lu J. Sham

Any basic digital electronic device involves two states, the famous 0 or 1 of binary logic. As the device is made smaller and smaller, the quantum nature of the system begins to appear. In quantum mechanics, we attach a probability to the occupation of each state. In addition, we are interested in the phase difference of the wave functions of these two states when the system is excited from one state to the other. This additional quantum property is known as coherence, and the dynamics of coherence is much studied in quantum optics. The problem with semiconductors, however, is that the optical coherence lasts no more than a few picoseconds, and only when the system is much cooler than the liquid nitrogen temperature. Neither condition enhances the prospects for building a coherent semiconductor device. Nevertheless, an exploration of coherent spin states for a quantum device has begun. The concept of coherence between two spin states was in fact borrowed by quantum optics. As reported on page 1284 of this issue, Kikkawa *et al.* (*1*) have induced the coherence between the two spin states of the optically excited electron and have discovered an environment which does not disturb this coherence for several nanoseconds, which persists even at room temperature. This is a necessary first step in the exploration of coherent spin dynamics in a semiconductor.



Effect of light. On the right, a light pulse is shown with an electric vector rotating in the sense of the purple arrow. On impinging on the crystal on the left, it excites electrons with spins pointing in the propagating direction of light. Like a gyroscope, the magnetic field **B** tries to bring the electron spin to alignment but only succeeds in making the spins precess about the magnetic field as shown by the yellow circles. The electron spin dynamics is monitored by a beam of light whose polarization initially lies in the vertical plane. The plane of polarization is rotated on reflection depending on the electron spin direction (Kerr rotation). The result is recorded as a function of time as shown by the damped sinusoidal trace below.

Coherent quantum devices are important not just because they contain one more piece of information but because they preserve quantum properties in a chain of such devices without the interference of observations except at the preparation and at the end of the process. For example, if each elementary device is a logic gate, then the chain of gates forms a quantum computer. Remarkable research in quantum computation theory (*2*) has shown that such a computer could factorize a large integer much faster than the traditional computer. A logic gate consisting of a trapped ion or an atom passing through an optical cavity has been demonstrated to work (*2*). The decoherence time is long (microseconds), but the devices work at very low temperatures, so a long chain of such devices is impractical.

Researchers then turned to ensembles of atoms or electrons carrying spins (*3*): because the spins are "up" or "down," they form a kind of natural binary logic. The attempt to incorporate spin in electronics has been stimulated by the ability to inject spin-polarized electrons from a ferromagnetic material to a semiconductor (*4*) or metal (*5*). But rather than being coherent devices, these spin transistors still have classical two-state properties. Kikkawa *et al.* (*1*) use a more conventional method of producing electron spins in semiconductors by optically exciting the electron with a specific spin di-

The author is in the Department of Physics, University of California at San Diego, La Jolla, CA 92093-0319, USA. E-mail: lsham@ucsd.edu

rection by means of a rotating electric vector of light (see figure). Conservation of angular momentum determines how the light pulse is coupled to the electron spin. With the input into the device and the measurement both accomplished by optical means, it might be possible to limit the time of each operation to the nanosecond range. The spin relaxation time found by Kikkawa fits in well with this range. The authors are careful to note that their method of measuring the long spin memory time, while establishing limits to the external sources of spin decoherence, does not rule out decoherence of individual spins involving mutual electron spin interaction.

In metals the conduction electron spin relaxation time decreases drastically with increasing temperature because of increasing lattice vibration, which affects the electron spin coherence through the spin interaction with its orbital motion (6). It is then a puzzle why the spin relaxation time in the semiconductor system of Kikkawa *et al.* (1) is so weakly temperature dependent.

Kikkawa *et al.* find that doping (that is, the introduction of electrons into the system) increases the spin relaxation time by a factor of 10 to 100. This effect occurs only if the excited electron density is a sizable fraction of the doped electron density. How does this sea of electrons, which has no net spin, help to maintain the spin coherence of the excited electrons? One possibility is the polarization of the electron sea by the optically excited electrons with a common spin direction. The Coulomb interaction among the electrons creates a collective spin that is then not easy to perturb. The spin polarization of the electron sea had earlier been observed (7), but the relaxation time was of the order of 100 ps at 10 K.

The long spin relaxation time found by Kikkawa *et al.* means sufficient time for controlling the spin dynamics. This is an important first step toward using semiconductor systems for coherent quantum devices. The fundamental physics of this phenomenon is interesting and could be very rich because it depends on a variety of interactions effects. The next step is to see if quantum coherence control is feasible. The construction of a quantum logic gate would be an encouraging demonstration of the possibility of coherent quantum semiconductor devices.

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GENETICS

Yeast as a Model Organism

David Botstein, Steven A. Chervitz, J. Michael Cherry

The first complete DNA sequence of a eukaryotic genome, that of the yeast *Saccharomyces cerevisiae*, was released in electronic form more than a year ago (1). No doubt, each member of the international consortium of yeast biologists made the argument to his or her own funding agency in Europe, Japan, Britain, Canada, or the United States that this yeast would be a fine "model organism," useful for interpreting and understanding human DNA sequences. How right were they?

mologs. We compared (4) all yeast protein sequences to the mammalian sequences in GenBank [EST (expressed sequence tag) databases were not included]. The result (see the table) is encouraging: For nearly 31% of all the potential protein-encoding genes of yeast (open reading frames, or ORFs), we found a statistically robust homolog among the mammalian protein sequences (5). This is clearly an underestimate, as the databases surely do not yet contain the sequences of all mammalian proteins or even representatives of every protein family. Many of these similarities relate individual domains, and not whole proteins, no doubt reflecting the shuffling of functional domains characteristic of protein evolution.

Mammalian homologs (based on *P* value)

P value	Number of ORFs at *P* value or lower	Percent of total ORFs (n = 6223)	Percent of ORFs with unknown function
1×10^{-10}	1914	30.8	34
1×10^{-20}	1553	25.0	30
1×10^{-40}	1083	16.8	26
1×10^{-60}	784	12.6	23
1×10^{-80}	576	9.3	22
1×10^{-100}	442	7.1	21
1×10^{-150}	221	3.6	23
1×10^{-200}	101	1.6	25

It was clear long before the systematic sequencing of genomes began that there are genes in yeast and mammals that encode very similar proteins (2). Some homologies—including proteins of molecular systems (for example, the ribosomes and cytoskeletons)—were no surprise. Some were quite unexpected, however. A particularly arresting early example was the discovery in yeast of two close homologs (*RAS1* and *RAS2*) of the mammalian *ras* proto-oncogene; yeast cells lacking both genes are inviable. In 1985 this system was the occasion for the first of many deliberate tests of functional conservation: The mammalian H-*ras* sequence was expressed in a yeast strain lacking both RAS genes, with the remarkable result that viability was restored, indicating a profound conservation not only of sequence, but also of detailed biological function (3).

With the entire yeast genome sequence in hand, we can estimate how many yeast genes have significant mammalian ho-

The authors are in the Department of Genetics, Stanford University School of Medicine, Stanford, CA 94305, USA. E-mail: botstein@genome.stanford.edu

Even though *S. cerevisiae* is among the best-studied experimental organisms, 60% of its genes still have no experimentally determined function. Of these, the majority nevertheless have some similarity or motif suggesting possible functions, leaving about 25% (by actual count) with no clue whatever. In compiling the data in the table, we observed that genes with homology to mammalian sequences are much less likely to have nothing experimental known of their function. Only 34% of the entire set of yeast genes with mammalian homologs have no function listed in the *Saccharomyces* Genome Database; compared to less than 25% of the genes having the strongest homology. We do not know the reason for this, although we do not rule out the optimistic idea that yeast biologists have succeeded in concentrating on the most important genes (those most likely to be conserved).

The likelihood that a newly discovered human gene will have a yeast homolog with