The magnetic world of bubble domains

Magnetic bubbles may be put to use in computer memories by the end of this year

by Dietrick E. Thomsen

Magnetic fields in solid magnetic materials are generated by the spin and orbital motions of certain of the electrons in the materials. Since the electrons are electrically charged, their circular motions constitute electric currents, and the currents generate magnetic fields. The fields of neighboring electrons tend to align themselves nearly parallel to each other so that field orientation changes only gradually through a sample of material.

Some magnetic materials have preferred magnetic axes: The electronic fields find it easiest to align themselves along a particular direction in the crystal. The fields may point in either direction along the preferred axis, and domains—regions in which the fields all point one way—tend to alternate with domains where the fields point the other way. Between the domains are walls in which the field direction reverses itself over a distance of several hundred electrons.

Any physical system tends to go to the lowest energy state it can reach. Since a piece of material with several domains in it has a lower magnetostatic energy than it would have if all its electronic fields were aligned in the same direction, domains tend to proliferate. Typically domains will continue to form and subdivide until the energy stored in the domain walls cancels the energy saved by further subdivision.

In the low-energy state thus reached, there appears a pattern of irregularly shaped, intertwined strip domains. Some of these reach the edges of the chip of material; others are entirely within the chip, island domains surrounded by a single continuous wall.

The formation of magnetic domains, their changing shapes and the motions of their walls have been a staple topic of investigation in solid-state physics for a long time. In 1967 Dr. Andrew H. Bobeck of the Bell Telephone Laboratories in Murray Hill, N.J., reported that under certain conditions island domains could be forced to condense into small cylindrical or bubble domains. Drs. Umberto F. Gianola, R. C. Sherwood and William Shockley share credit with Dr. Bobeck for the discovery.

Thousands of bubble domains can be generated in a square inch of material. They can also be made to move around in the material. These two properties give them a high potential for application in computer memories and similar devices. Bell Labs has mounted a research and development effort that, according to Dr. Bobeck, hopes to produce devices using magnetic bubbles by the end of the year. Smaller efforts are under way in other places, notably at IBM.

At a Conference on Magnetism and Magnetic Materials in Miami Beach last November contributions to the discussion of magnetic bubbles came from Sperry Rand and North American Rockwell as well as Bell Labs and IBM. Drs. F. A. de Jonge, W. F. Druyvesteyn A. G. H. Verhulst of the Philips Research Laboratories at Eindhoven, The Netherlands, reported a new variant, a hollow bubble or ring domain.

Bubble domains were first found in a class of materials called orthoferrites, compounds of rare earths, iron and oxygen. They have the general chemical formula $RFeO_3$, where R is any of the rare earths or the element yttrium. If sheets of these materials are prepared so that their preferred magnetic axis is perpendicular to the surface, the natural pattern of intertwined strip domains can be seen by shining polarized light through the sheet, since the electrons in the material interact differently with the light according to their orientation.

Applying a magnetic field opposite to the field in the island domains causes them to shrink until, at a certain critical field strength, the island becomes an almost perfect circle. The bubbles are a few microns in diameter. They may be moved around by applying unbalanced magnetic forces to their walls. They may be annihilated by increasing the biasing field beyond a certain critical maximum, and they may be split by applying a pulsed field.

All these operations are performed by running currents through properly shaped circuit elements placed near the sheet of magnetic material. Wedges and loops are among those under study.

External circuit elements can be used to set up channels in the material, and the memory will answer yes or no to a given question depending on whether there is a bubble in a given channel or not. One of the advantages over other sorts of memory arrangement is that there is not any physical electrical connection between the memory element and the external circuitry. The presence or absence of the bubbles is sensed by interactions between their magnetic fields and those of the external circuit elements. "It's more like

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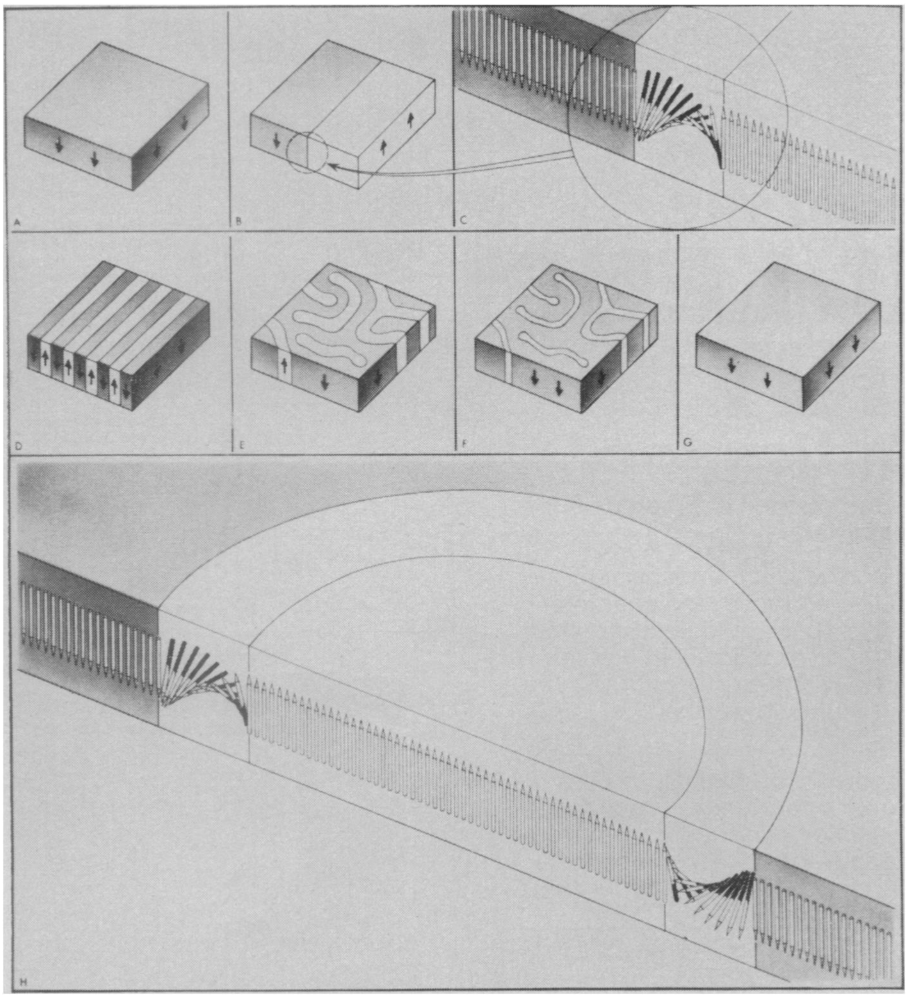
Bobeck: A magnetic memory more like a piano roll than an electronic device.



Formation of bubble domains: A sample of orthoferrite material may have all its electronic magnetic fields pointed in one direction (A). The system is less energetic if domains of opposite direction alternate (B). Although the configuration (D) can be stable, that of (E) is more likely to form. An external biasing field causes the domains to shrink to bubbles (G, H).

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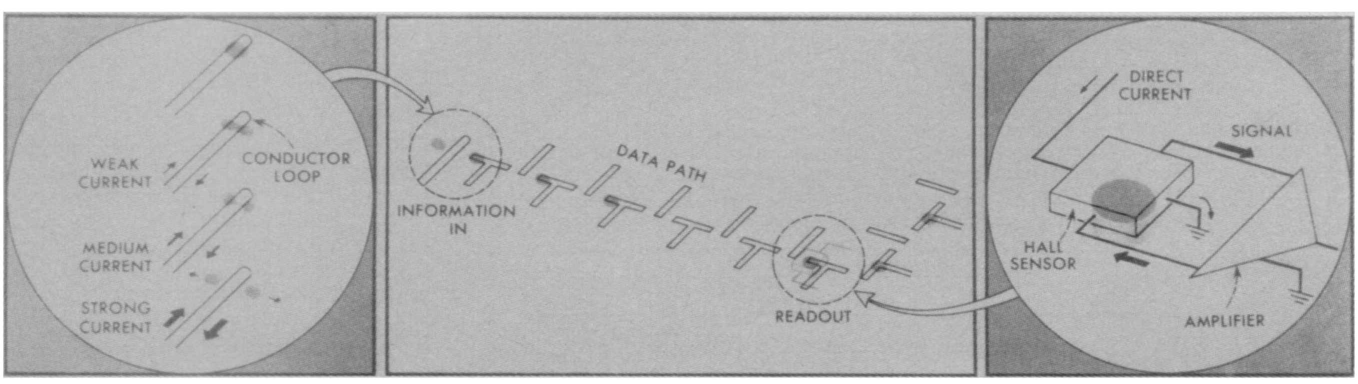
player piano work than electronics," says Dr. Bobeck.

Research has concentrated on the nature and behavior of the bubbles and attempts to find new materials in which they can be made to appear. During the past winter garnet was added to the list of magnetic bubble materials. This is particularly advantageous, says Dr. Bobeck, because garnet is a cubic crystal (the orthoferrites are orthorhombic crystals) and is easier to grow epitaxially on a substrate of different material, an important point when it comes to fabricating actual memory elements.

Ultimately the hope is to be able to cook up magnetic bubble materials with a wide range of bubble densities and bubble mobilities. This could give memory elements with densities between a few thousand and ten million bits of information per square inch. It could also give a wide range of speeds of access to the information.

One of the major advantages of the bubble materials, Dr. Bobeck says, is that they occupy a range of access times that falls between those of mechanical devices like reels and tape and those of ferrite core memories. Thus they fill an important technological gap by adding substantially to the range of available access times. The fastest access is not always the best; the optimum access time for any application depends on the process in which the information is to be used.

The higher the bubble density, and therefore the bit density, the lower will be the cost of the memory materials. The amounts of power necessary to manipulate the bubbles are also very small, and that too will lower cost. All in all the prospect is for an efficient, cheap form of memory device. □



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A dynamic magnetic-bubble memory element: In this idealized picture bubbles are formed by current in the loop at left and move through the material. Information is read out when they reach a sensing element at right. Bars and T patterns etched in permalloy produce unbalanced magnetic forces that make the bubbles move.