which are the source of a large number of alien species introduced into the Great Lakes. Their model pinpointed 22 fish species that show the characteristics of good invaders, of which five (including the European perch, *Perca fluviatilis*, and Eurasian minnow, *Phoxinus phoxinus*) are predicted to become nuisance species. The ecosystem impacts of further introductions to the Great Lakes are difficult to assess, but given the clear potential for these to happen, measures should be put in place immediately to prevent them. Such measures could include treatment of ballast waters discharged by ships and prohibiting the importation of high-risk species for the aquaculture, pet, and live-bait industries.

In the second study, a similar predictive approach is taken by Lens and colleagues (*3*), who examine the persistence of species in fragmented habitats. This time, the focal taxon is birds and the ecosystem is the Taita Hills forest of southeast Kenya, which is part of the Eastern Arc biodiversity hotspot (see the figure). These high hills were once blanketed by a continuous cover of humid forest, but after years of deforestation for conversion to agriculture, only 12 fragments remain, the largest of which spans an area of only 179 ha. Which species are likely to persist and which are likely to be lost when the habitat is fragmented to such an extent?

Lens *et al*. show that the more mobile bird species fare best, but equally important is the sensitivity of species to the environmental deterioration that occurs *within* fragments. Degradation inside forest patches results, for example, from selective removal of mature trees for building materials and introduction of exotic species for small-scale plantations. The index of sensitivity was based on a clever comparison between the asymmetry in left and right tarsus lengths of birds living in the most degraded forest fragment, and that of museum specimens collected several decades before habitat deterioration. The larger the departure from historical asymmetry, the more sensitive is the species to habitat change. This link is based on previous studies showing that the bilateral traits of birds living in more degraded habitats are more asymmetric (*5*), and that birds with asymmetric characteristics die at an increased rate (*6*).

These two seemingly disparate studies have two remarkable features in common. The first is that the best models that the authors devised to explain their respective problems incorporated very few parameters (three or four in the case of Kolar and Lodge; only two in the case of Lens *et al.*). The second is that these simple models explain a huge amount of the variation in the respective data sets (more than 80% in both cases). This gives the models great predictive power, but their usefulness will depend on their general applicability and on how easily the necessary parameters can be measured. This is where the studies differ. Kolar and Lodge were able to extract all of their information from published literature or from questionnaires. By contrast, the two parameters in Lens *et al.*'s model required 6 years of labor-intensive fieldwork and the availability of museum specimens to compare levels of fluctuating asymmetry. In addition, there is a good chance that Kolar and Lodge's predictions will apply broadly to aquatic ecosystems, and unfortunately, there are numerous waterbodies riddled with introduced fish that can be used as test cases. On the other hand, the conclusions of Lens *et al.* may be more system-specific. The Taita Hills forest fragments are still close enough together to allow dispersal, giving mobile species an advantage. However, mobility will be irrelevant when fragments are too far apart. How far is too far can be predicted by metapopulation theory (*7*). Together, these studies show the value of using ecological theory to guide the search for general rules in conservation biology, and suggest that complex problems may sometimes have simple explanations.

References

1. IUCN, *2002 IUCN Red List of Threatened Species*, www.redlist.org.
2. C. S. Kolar, D. M. Lodge, *Science* **298**, 1233 (2002).
3. L. Lens, S. Van Dongen, K. Norris, M. Githiru, E. Matthysen, *Science* **298**, 1236 (2002).
4. A. K. Sakai *et al.*, *Annu. Rev. Ecol. Syst.* **32**, 305 (2001).
5. L. Lens, S. Van Dongen, C. M. Wilder, T. M. Brooks, E. Matthysen, *Proc. R. Soc. London Ser. B* **266**, 1241 (1999).
6. L. Lens, S. Van Dongen, E. Matthysen, *Conserv. Biol.* **16**, 497 (2002).
7. I. Hanski, *Metapopulation Ecology* (Oxford Univ. Press, Oxford, 1999).

PERSPECTIVES: MATERIALS SCIENCE

Talking Ceramics

Terrell A. Vanderah

In the last three decades, telecommunications have been completely transformed. Devices such as cell phones are now so common that many consumers are forgoing the hard-wired versions altogether.

This remarkable change could not have taken place without several key historical events, such as Marconi's first wireless transmission across the Atlantic Ocean in 1901 and the discovery of the transistor almost 50 years later (*1*). Also critical was the discovery of unique ceramic materials that could be used as dielectric resonators and filters to store and transfer microwave communication signals.

Richtmyer coined the term "dielectric resonator" in 1939 (*2*), when he wrote, "if a long dielectric cylinder were bent into a ring and the ends joined together, it would guide the waves round and round indefinitely" (see the figure). He concluded that "such an object would act as an electrical resonator," possibly useful in electrical communication, because the resonant frequency would radiate from the resonator through free space, and thus could be detected by other (receiving) devices.

The size of the resonator is inversely related to the dielectric constant, *K*, of the internal medium. The first versions, which used air as the dielectric ($K \approx 1$), were too large for practical use. Subsequent designs with a ceramic such as TiO_2 ($K \approx 100$) allowed size reduction by a factor of 10. However, they also proved impractical because the resonant frequency, and hence the communication signal, were strongly temperature dependent and would drift as operational temperatures varied (for example, on hot versus cold days).

This technological barrier was overcome in the 1970s by the discovery of $Ba_2Ti_9O_{20}$-based ceramics (*3*, *4*), which have the required set of properties: a high dielectric constant, low dielectric loss (conversion of signal to heat, which broadens the signal), and temperature-stable resonant frequency (*5*–*8*). In the next two decades, cellular base station technologies proliferated (see the second figure), and the volume and weight of handheld devices plummeted.

Today, dielectric ceramics are commercially important as enabling materials for resonators, filters, and other key components in microwave communications systems. The global market for the ceramics is on the order of $400 million; the markets for the resulting devices and components, and for the end-user systems, are ~10 and ~100 times that size, respectively.

Despite their technical importance and widespread use, very few ceramic materials are known that meet the stringent property requirements (*5*–*7*) imposed by the operating frequency, required power levels, and type of application (base station or handheld device). Only two ceramic materials are optimized for 900-MHz base sta-

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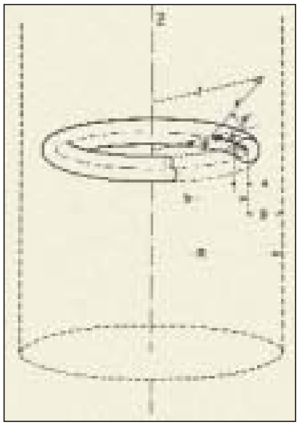
The author is at the National Institute of Standards and Technology, Gaithersburg, MD 20899, USA. E-mail: terrell.vanderah@nist.gov

tion applications, one based on $ZrTiO_4$ and the other on $CaTiO_3$-$NdAlO_3$ (both with $K \approx 45$). For 2 GHz and higher, only one commercially available ceramic, the tantalate $Ba_3ZnTa_2O_9$ ($K \approx 30$), has the required ultralow dielectric loss, apparently attributable to the presence of Ta^{5+}. The high cost of the raw material, Ta_2O_5, presents materials scientists with a pressing challenge to understand the role of tantalum and replace it with a less costly element.



The key to the wireless revolution. This dielectric ring resonator, proposed by Richtmyer in 1939 (*2*), uses air as the dielectric. Cylindrical coordinates, pseudo-cylindrical coordinates, and dimensions are indicated. The subsequent discovery of temperature-stable ceramics with high dielectric constants (K ~ 36) permitted the miniaturization of such resonators for use in cellular base stations.

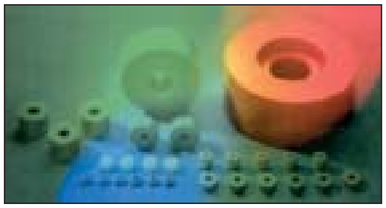
Next-generation designs, spectral crowding, and commercial realities create a continuous need to reduce dielectric loss and lower the cost of ceramic resonators and filters. This presents important challenges to materials scientists because the fundamental physics that give rise to the desired properties, especially dielectric loss and temperature stability, are not well understood. Furthermore, the dielectric loss of a material, which limits frequency selectivity, is heavily influenced by extrinsic factors such as microstructure, defects, and porosity. Fundamental understanding of microwave ceramics is needed to improve existing materials and discover new materials for advanced applications.

Many dielectric ceramics form with perovskite-related ABO_3 structures. In this crystalline arrangement, A is a large cation ideally surrounded by 12 oxygen atoms, and B is a smaller cation, surrounded by six oxygen atoms located at the vertices of an octahedron. In the highly symmetric cubic arrangement, both the A and B cations can achieve ideal bond distances to oxygen that satisfy their different sizes and electronegativities. However, in most perovskites, ideal A-O and B-O bond distances are not geometrically compatible, resulting in distorted lower symmetry structures.

Reaney *et al*. (*9*, *10*) have established clear correlations between these structural effects, which can be controlled by the choice of cation, and the temperature dependence of the dielectric constant (or resonant frequency). Most recently, they have focused on how dielectric loss depends on the distribution of A-O and B-O bond distances in the structure, which reflects chemical strain.

Davies has shown that subtle structural effects such as cation ordering patterns can dramatically influence the dielectric loss properties of microwave ceramics (*7*, *11*, *12*). Levin also observed such effects (*13*) in a systematic study of a perovskite-like system, $Ca(Ca_{1/3}Nb_{2/3})O_3$, which can form three polymorphs with different ordered patterns of Ca^{2+} and Nb^{5+} in the octahedral sites. Even though the chemical formula is identical for all three forms, Levin observed substantial differences in dielectric behavior at microwave frequencies. He found a systematic dependence of the dielectric constant and its temperature dependence on the varying degrees of bond distortion in the structures.

Cockayne and Burton have successfully computed the phonon spectrum and dielectric constant for $CaTiO_3$ using first-principles methods (*14*). Their results were subsequently confirmed by experiment (*15*). Kamba *et al*. (*16*) have elucidated relationships between phonon spectra and crystal structure for $A_5B_4O_{15}$-type ceramics, which have perovskite-related crystal structures. Zurmuehlen *et al*. have systematically characterized the intrinsic dielectric losses of perovskite ceramics by spectroscopic methods (*17*). Much more research is needed in this area to reveal universal relationships among dielectric properties, chemistry, and crystal structure.



Talking ceramics. Such dielectric ceramic resonators are used in cellular base stations to store and transmit signals to handheld devices such as cell phones.

The absence of basic materials data is also a continuing problem. According to Taki Negas (TCI Ceramics Inc., Hagerstown, Maryland) (*18*), the starting point for any new complex material is chemistry and processing (*6*), which requires knowledge of high-temperature phase compatibility in simple systems involving alkaline-earth and other metal oxides. According to Negas, "it's terribly frustrating to have ideas on new, complex systems, and then find out that fundamental thermochemical and phase equilibria data for the simple subsystems are not available. Industry then either wastes time doing this basic work, or must use chemical analogies to make guesses, which are often wrong" (*19*).

Researchers recently convened in York, UK, for the Microwave Materials and Their Applications meeting (MMA 2002) (*20*) to exchange ideas on the most recent research, development, and applications of microwave materials. Recent work seeking new microwave ceramics was reported by Peter Davies (University of Pennsylvania, Philadelphia), who described the synthesis of new titanate, tantalate, and niobate perovskite-type compounds with deliberate mixing of different types of B cations to achieve cation ordering patterns associated with good dielectric properties.

Industrial speakers provided valuable information on short- and long-term technical needs. Hannes Medelius (Ericsson AB, Stockholm) noted that the most pressing immediate need is for inexpensive, temperature-stable ceramics with properties similar to those of the tantalates. Both David Cruickshank (Trans-Tech Inc., Adamstown, Maryland) and David Rhodes (Filtronic plc, Shipley, UK) pointed out that in the longer term, electrically tunable filters would provide substantial system benefits. Such filters require the development of new materials with low dielectric loss and with dielectric constants that can be changed by applying voltage. The latter phenomenon has only been demonstrated in ferroelectric ceramics, which have high losses (they absorb most of the signal).

Possibly the least conventional research pertinent to microwave materials was described by John Halloran (University of Michigan, Ann Arbor), who explores "metamaterials," or ordered nanocomposites, under a DARPA program. The possibilities of metamaterials hinge on the theoretical possibility of negative values for the dielectric constant, magnetic permeability, and index of refraction (*21*). Deliberately textured materials with periodic variations in dielectric constant may enable the fabrication of miniature resonators and filters (*22*), which are of particular importance in handheld wireless devices.

Future improvements of handheld devices also require new materials, as described by Danilo Suvorov (Jozef Stefan Institute, Ljubljana, Slovenia), to achieve increased functionality. Today's circuits require discrete components—resistors, capacitors, etc.—each taking up a lot of space. Multilayer ceramic integrated circuit (MCIC) technology eliminates discrete components by organizing them into a single module that performs all passive and active functions. To accomplish this, ceramics with the required dielectric and

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magnetic properties must be found that can be processed next to metal layers at relatively low temperatures (<900°C), with little or no chemical interaction that would degrade properties.

The technical problems presented by microwave materials pose rich scientific challenges to the materials science community. Depending on the operating frequency and application—base station infrastructure or handheld device—materials with a wide range of dielectric and magnetic properties are needed, all with improved performance at lower cost. As engineers develop new concepts and designs for tomorrow's communication systems, they will be relying on progress in understanding and controlling these materials.

References and Notes

1. W. R. Snyder, C. L. Bragaw, *Achievement in Radio* (NBS Spec. Pub. 555, U.S. Government Printing Office, Washington, DC, October 1986).
2. R. D. Richtmyer, *J. Appl. Phys.* **10**, 391 (1939).
3. H. M. O'Bryan, J. Thomson, J. K. Plourde, *J. Am. Ceram. Soc.* **57**, 450 (1974).
4. T. Negas *et al.*, *Am. Ceram. Soc. Bull.* **72**, 80 (1993).
5. R. J. Cava, *J. Mater. Chem.* **11**, 54 (2001).
6. T. Negas, G. Yeager, S. Bell, R. Amren, in *Chemistry of Electronic Materials* (NIST Spec. Pub. 804, U.S. Government Printing Office, Washington, DC, 1991), pp. 21–37.
7. P. K. Davies, in *Materials and Processes for Wireless Communications*, T. Negas, H. Ling, Eds., vol. 53 of *Ceramic Transactions* (American Ceramic Society, Westerville, OH, 1995), pp. 137–151, 179–196.
8. S. Penn, N. Alford, in *Handbook of Low and High Dielectric Constant Materials and Their Applications, Vol. 2,* H. S. Nalwa, Ed. (Academic Press, New York, 1999), chap. 10.
9. I. M. Reaney, E. L. Colla, N. Setter, *Jpn. J. Appl. Phys.* **33**, 3984 (1994).
10. I. M. Reaney *et al.*, *Phil. Mag.* **81**, 501 (2001).
11. R. Christofferson, P. K. Davies, X. Wei, T. Negas, *J. Am. Ceram. Soc.* **77**, 1441 (1994).
12. P. K. Davies, J. Tong, T. Negas, *J. Am. Ceram. Soc.* **80**, 1727 (1997).
13. I. Levin *et al.*, *J. Solid State Chem.* **156**, 122 (2001).
14. E. Cockayne, B. P. Burton, *Phys. Rev. B* **62**, 3735 (2000).
15. V. Zelezny *et al.*, *Phys. Rev. B*, in press; preprint: Eric.Cockayne@nist.gov.
16. S. Kamba *et al.*, *J. Appl. Phys.* **89**, 3900 (2001).
17. R. Zurmuehlen *et al.*, *J. Appl. Phys.* **77**, 5351 (1995).
18. The identification of a commercial firm does not imply endorsement or recommendation by the National Institute of Standards and Technology.
19. T. Negas, personal communication.
20. York, UK, 1 to 3 September 2002 (see www2.umist.ac.uk/material/research/microwave/meetings/MMA2002/Default.htm). The meeting was organized by the Microwave Dielectrics Network (www.umist.ac.uk/microwave).
21. J. Pendry, *Phys. World* **14**, 47 (September 2001).
22 W. J. Chappell, M. P. Little, L. P. B. Katehi, *IEEE Micro. Wire. Comp. Lett.* **11**, 246 (2001).

PERSPECTIVES: NEUROBIOLOGY

A Glial Spin on Neurotrophins

Barbara L. Hempstead and James L. Salzer

The membranous myelin sheath that surrounds the axons of neurons enables the efficient and rapid propagation of action potentials, which is essential for the smooth operation of the vertebrate nervous system. The myelin sheath is produced by nonneuronal glial cells: Schwann cells in the peripheral nervous system (PNS) and oligodendrocytes in the central nervous system (CNS). During development, glial cells and neurons depend on each other for survival and differentiation. Among the most dramatic but least understood of these cell-cell interactions are those initiating the formation of myelin. Myelination involves striking changes in the differentiation and morphology of glial cells (see the figure). In addition, axons regulate the myelination program of glia during development through a combination of positive and negative signals (*1*). These still-mysterious signals ensure that myelination is restricted to specific types of axons and is switched on at the appropriate time. On page 1245 of this issue, Cosgaya *et al*. (*2*) report that nerve growth factors called neurotrophins are emerging as both positive and negative modulators of myelination. In particular, they show that the p75 neurotrophin receptor positively regulates myelination by Schwann cells in the PNS.

In earlier work, Cosgaya and colleagues described the opposing effects of neurotrophins on myelination (*3*). They showed that addition of brain-derived neurotrophic factor (BDNF) to cocultures of Schwann cells and neurons, or injecting BDNF next to the developing sciatic nerve promoted myelination; in contrast, neurotrophin-3 (NT3) inhibited myelination in both sets of experiments. Interestingly, BDNF, but not NT3, persisted at significant levels in the cocultures through the onset of myelination, suggesting that this neurotrophin serves as a promyelinating signal. These findings are strikingly similar to those of another study showing that BDNF is a paracrine signal that promotes the differentiation of avian Schwann cells cocultured with neurons, and that NT3 is inhibitory (*4*). This study also revealed that neurons, rather than glial cells, are the major source of BDNF (*4*).

Neurotrophins mediate their effects by binding to two classes of receptor: the Trk receptor tyrosine kinases and the p75 receptor, a member of the tumor necrosis factor receptor superfamily that binds to all neurotrophins. Nerve growth factor (NGF), BDNF, and NT3 bind selectively to TrkA, TrkB, and TrkC receptors, respectively; truncated forms of each of these Trk receptors also exist (*5*). Both Schwann cells and neurons express neurotrophin receptors, and so neurotrophins may act on glial cells either directly or indirectly (through modulation of the myelination signals from axons). The neurons used in the Cosgaya *et al.* study (*2*) were dependent on NGF for their survival but not on BDNF or NT3, suggesting that BDNF and NT3 regulate myelination through direct effects on Schwann cells.

Schwann cells express p75 during development, prior to myelination, as well as kinase-active TrkC and kinase-inactive, truncated isoforms of TrkB and TrkC (*6*). Cosgaya *et al*. now demonstrate that p75 mediates the myelin-promoting effect of BDNF and that kinase-active TrkC transduces the myelin-inhibitory effect of NT3 (*2*). Thus, antibodies to p75, but not antibodies to TrkB, blocked the myelin-promoting effect of BDNF; pharmacological inhibition of Trk kinase activity blocked the ability of NT3 to inhibit myelination. Peripheral nerves of mice deficient in p75 are hypomyelinated and, as Cosgaya *et al*. show (*2*), are unresponsive to the myelin-promoting effects of BDNF. Because p75 is rapidly down-regulated at the onset of myelination (*1*), p75 is likely to promote the initial axon-glial interactions that precede, and are required for, myelination rather than myelination itself (see the figure). Among these early events are Schwann cell migration along and initial ensheathment of axons, both of which are impaired in p75-deficient mice (*7*). These findings also imply that p75-dependent effects reflect the activity of the p75 receptor expressed by Schwann cells and not that expressed by axons. However, to distinguish between these two possibilities, it will be necessary to analyze nerves from mice lacking p75 only in Schwann cells, or to culture Schwann cells from p75-deficient mice with wild-type neurons.

What downstream signaling molecules might distinguish the myelin-promoting effects of BDNF-induced p75 activation from the myelin-inhibitory effects of NT3-induced TrkC activation? Because p75 and Trk receptors use many unique intracellular signaling pathways (*5*, *8*), Schwann cells may interpret the effects of local neurotrophin ligands through differential receptor binding and activation. The pathways downstream of the Trk receptors are well characterized, and further analysis should provide new insights into the negative regulation of myelination (*5*). Elucidating how activation of p75 promotes myeli-

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B. L. Hempstead is in the Department of Medicine, Weill Medical College of Cornell University, New York, NY 10021, USA. E-mail: blhempst@med.cornell.edu J. L. Salzer is in the Department of Cell Biology and Department of Neurology, New York University School of Medicine, New York, NY 10016, USA. E-mail: jim.salzer@med.nyu.edu