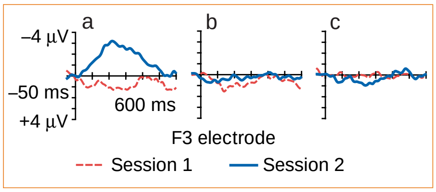

Figure 1 Mismatch negativity (MMN) results from two recording sessions, one in the evening and one the next morning, of responses to deviant speech sounds (y/i) in three groups (one experimental and two control groups) of human newborns. **a,** Experimental group, which underwent nocturnal training. The significant difference between results from the pre- and post-training sessions in this group suggests that sleeping newborns are better able to discriminate the speech sounds /y/ and /y/i/ after training. **b, c,** Control group 1 (**b**), which was not exposed to any training, and control group 2 (**c**), which was trained to discriminate between other vowel sounds, show no difference between the two sessions. The electro-encephalographic output was averaged and digitally filtered (1–30 Hz) at two frontal and two central scalp sites as well as two eye electrodes (for exclusion criteria and other details, see ref. 6). Mean MMN amplitude was calculated relative to a 60-ms period centred on the largest peak between 150 and 400 ms from stimulus onset in all except the eye electrodes. The presence of MMN was tested by using two-tailed *t*-tests for dependent samples.

1) and the next morning (session 2); the experimental group also had a session the following evening (session 3). Control group 1 received no training during the night, but the experimental group and control group 2 were exposed to nocturnal auditory training during sleep between sessions 1 and 2. Each MMN recording session lasted for just under 1 hour; in the experimental group, the training session was carried out over 2.5–5.0 hours. The experimental group and control group 2 were treated identically in sessions 1 and 2, except that during training the second control group was presented with /a/ and /e/ sounds instead of /y/ and /i/.

Throughout all sessions in all groups, a randomized sequence consisting of standards and deviants was presented online. In addition to pre-training stimuli with the experimental group, during session 2 we presented stimuli of different pitches that were otherwise identical: this was to determine whether the infants were simply learning acoustical discrimination or whether their increased discrimination ability was related to speech sounds.

The results from both pre- and post-training sessions showed that MMN responses to the acoustically 'easier' /i/ deviant stimulus ($t(14)$ varying between 2.5–5.8) were statistically significant in all groups. In session 1, the MMN amplitude was significantly smaller for the deviant /y/i/ than for /i/ in all groups, but no differences were found between the groups ($F(1,84)$, 8.62, $P < 0.004$) in a three-way ANOVA analysis (group X, stimulus X, electrode (F3, F4, C3, C4)). The difference between sessions 1 and 2 in all groups and for both deviants was separately tested by using a two-way ANOVA (session X, electrode). In both control groups, no statistical difference in MMN amplitude was found between sessions 1 and 2.

Our main finding was that experimental subjects learned to discriminate both deviants from the standard after training (Fig. 1). In this group, the MMN elicited by /y/i/ was not significant in session 1 (mean, -0.28; s.d. 2.19) but it was in session 2 (mean, -3.76; s.d. 2.04). The difference between sessions 1 and 2 was $F(1,28)$, 16.58, $P < 0.0003$. Moreover, the MMN response for the /i/ deviant increased strikingly in amplitude after training ($F(1,28)$, 27.57, $P < 0.00001$). There was no significant reduction in MMN amplitude between sessions 2 and 3 for either deviant in the experimental group.

The experimental group learned not only to discriminate between the stimuli to which they were exposed during training, but also between stimuli (not presented to them during training) that had different F0 values (pitch) but were otherwise identical. The differences obtained in session 2 in response to the trained and non-trained stimuli were tested by using two-way ANOVAs (deviant (trained and untrained), X electrode): no significant deviant effect was found for either deviant. Moreover, the experimental group exhibited a significant MMN response to both deviants in session 3, indicating that the training effect lasted for some time. In separate two-way ANOVAs (session X, electrode), no significant session effect was found for either deviant.

We have shown that newborns can assimilate auditory information while they are sleeping, suggesting that this route to learning may be more efficient in neonates than it is generally thought to be in adults.

M. Cheour*†, O. Martynova*, R. Näätänen‡§, R. Erkkola||, M. Sillanpää¶, P. Kero#, A. Raz☆, M.-L. Kaipio‡, J. Hiltunen*, O. Aaltonen, J. Savela**, H. Hämäläinen***

**Language and the Developing Brain Laboratory, Centre for Cognitive Neuroscience, and Department of Psychology, and **Department of Phonetics, University of Turku, 20100 Turku, Finland*
e-mail: marie.cheour@utu.fi
†BioMag Laboratory, Helsinki University Central Hospital, 00029 Helsinki, Finland
‡Cognitive Brain Research Unit, Department of Psychology, and §Helsinki Brain Research Centre, University of Helsinki, 00014 Helsinki, Finland
Departments of ||Obstetrics and Gynaecology, ¶Child Neurology, and #Pediatrics, Turku University Central Hospital, 20100 Turku, Finland
☆Sackler Institute for Developmental Psychobiology, Department of Psychiatry, Weill Medical College of Cornell University, New York, New York 10021, USA

1. Dave, A. S., Yu, A. C. & Margoliash, D. *Science* **282,** 2250–2254 (1998).
2. van Heteren, C. F., Boekkooi, P. F., Jongsma, H. W. & Nijhuis, J. G. *Lancet* **356,** 1169–1170 (2000).
3. Tallal, P. P., Miller, S. L., Bedi, G. G., Byma, G. G. & Wang, X. X. *Science* **271,** 77–81 (1996).
4. Kraus, N. *et al. Science* **273,** 971–973 (1996).
5. Näätänen, R. *et al. Nature* **358,** 432–434 (1997).
6. Cheour, M. *et al. Int. J. Psychophys.* **29,** 217–226 (1998).
7. Cheour, M. *et al. Nature Neurosci.* **1,** 351–353 (1998).
8. Cheour, M., Leppänen, P. H. & Kraus, N. *Clin. Neurophysiol.* **117,** 4–16 (2000).

Competing financial interests: declared none.

Microstructures

Spin-engineering magnetic media

The explosion in demand for increased data-storage density is driving the exploration of new magnetic media. Here we describe a new type of magnetic medium in which the spin configurations are engineered in chemically homogeneous magnetic films: regularly arranged in-plane and out-of-plane spin configurations are defined by altering the magnetic anisotropy. These spin-engineered media not only maintain the surface planarity but also the homogeneity of the magnetic materials, and our method is likely to find immediate application on account of its simplicity and ease of integration.

Two approaches are being used in the search for ultrahigh-density magnetic recording media. One is based on a conventional, continuous film medium, in which the storage density is increased by stabilizing the nanoscale magnetic domains in order to resist the thermal self-erasure effect[1]. The other depends on the patterning of magnetic films into magnetically isolated dots[2], with each dot containing two discrete magnetized states with equal but opposite magnetic moments. Each dot is thus able to store one bit of information.

We used a modulated single/polycrystalline substrate surface to modify locally the magnetic anisotropy in subsequently deposited magnetic films, which induces the desired artificial magnetic structure. Selective epitaxial growth introduces an alternation between single-crystal and polycrystalline structures in the film, according to the substrate patterning (Fig. 1a). Epitaxial Ni/Cu(001) films of appropriate thickness show perpendicular magnetization, which is due to the magneto-elastic interaction induced by the Ni/Cu(001) interface[3,4]. In contrast, the magnetization of polycrystalline nickel lies in the film plane because of the dominant demagnetizing field. The substrates used are GaAs(001) and two types of pattern were chosen: wire and dot array.

The arrays were obtained by lithography

and the subsequent lifting off of 1-nm-thick nickel (this thickness was chosen for simplicity — in principle, half a monolayer is sufficient for selective epitaxial growth). The ultra-thin nickel patterns were then oxidized in air to become ultra-thin nickel oxide templates. The patterned substrates were annealed to clean the surface before growing Cu(5 nm)/Ni(5 nm)/Cu(70 nm)/Co(1.8 nm) films at room temperature. The Cu/Co films are used as an underlayer[5] to promote epitaxial nickel growth on the substrate, with 5-nm-thick nickel displaying a stable perpendicular magnetization[3,6]. Films grown on the NiO templates are polycrystalline, whereas those grown directly onto the GaAs surface are single-crystal films. We examined the sample surface by atomic-force microscopy, which yielded roughness parameters in a similar range to that of epitaxial continuous Cu/Ni/Cu films[4].

The modulated magnetic structures were confirmed by magnetic-force microscopy (MFM) and magneto-optic Kerr-effect (MOKE) magnetometry. Figure 1b shows the MFM images of the dot and wire samples in the remanent state after saturation with a perpendicular field. The bright stripes in the images correspond to the out-of-plane nickel magnetization, which has a strong magnetic signal compared with that of the in-plane magnetization.

Figure 1c shows MOKE measurements in the field-perpendicular-to-film (polar) geometry. The perfectly square hysteresis loop obtained from the unpatterned epitaxial film indicates that only perpendicular magnetization exists (Fig. 1c, left). For the wire sample, however, the sharp switch at low field originates from the regions of perpendicular magnetization (Fig. 1c, right), whereas the gradual saturation in high field is caused by the presence of the in-plane magnetized regions.

The spin-engineering of this magnetic medium, which can be seen as the integration of patterned features into chemically homogeneous films, opens up new avenues for controlling the spin structure of magnetic materials. Our simulation results show that the patterned bit resolution can be smaller than 30 nm. Such modulated structures can be used as planar patterned magnetic media[7] without breaking the homogeneity of the magnetic film, which is essential for avoiding effects caused by reduced Curie temperature. Furthermore, the anisotropy-constrained magnetic walls are static in nature, which provides a reproducible switching mechanism, unlike that of the natural domain wall. Such a system could also be useful for studying magnetic dipolar and exchange interactions, for example, and domain-wall resistance in highly controlled geometric systems.

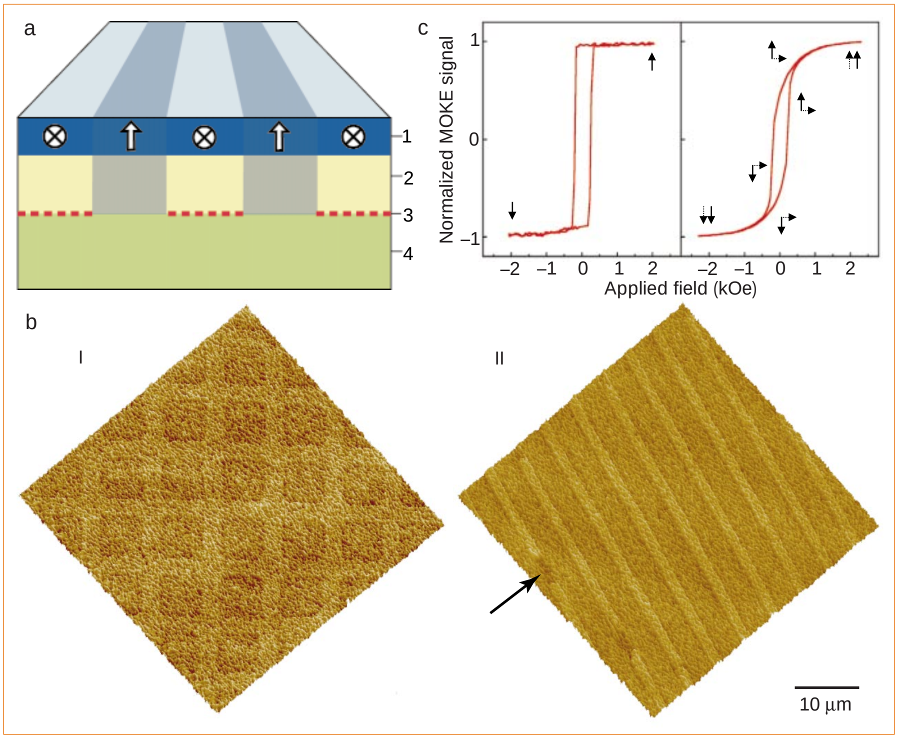

Figure 1 Selective epitaxy in spin engineering and magnetic characterization. **a,** Selective epitaxial growth of Cu/Ni/Cu/Co structure. Layer 1, magnetic layer of nickel; symbols: crosses, magnetization in the plane of the film; arrows: magnetization perpendicular to the film. Layer 2, Cu/Co underlayer. Ultra-thin NiO was used as the embedded template (layer 3) on a GaAs(001) substrate (layer 4). The wire arrays are 2 µm wide and separated by 4 µm; the square dots are 7 × 7 µm^2 and are separated by 3 µm. **b,** Magnetic-force microscopy (MFM) images of the dot (I) and wire (II) samples in zero field after perpendicular field saturation. Arrow indicates a switch of the perpendicular Ni induced by the external stray field of the MFM tip. **c,** Polar magneto-optic Kerr-effect (MOKE) hysteresis loops for the unpatterned reference sample (left panel) and the wire sample (right panel). Solid and dotted arrows indicate the magnetization orientation in the epitaxial and polycrystalline regions, respectively, of the Ni film.

S. P. Li*, W. S. Lew*, J. A. C. Bland*, L. Lopez-Diaz*, M. Natali†, C. A. F. Vaz*, Y. Chen†
**Cavendish Laboratory, University of Cambridge, Madingley Road, Cambridge CB3 0HE, UK*
e-mail: jacb1@phy.cam.ac.uk
†Laboratoire de Microstructures et de Microélectronique (CNRS), 196 Avenue Henri Ravera, 92225 Bagneux Cedex, France

---

1. Krusin-Elbaum, L., Shibauchi, T., Argyle, B., Gignac, L. & Weller, D. *Nature* **410,** 444–446 (2001).
2. Chou, S. Y. *Proc. IEEE* **85,** 652–671 (1997).
3. O'Brien, W. L. & Tonner, B. P. *Phys. Rev. B* **49,** 15370–15373 (1994).
4. Hope, S. *et al. Phys. Rev. B* **55,** 11422–11431 (1997).
5. Lew, W. S. *et al. J. Appl. Phys.* **87,** 5947–5949 (2000).
6. Bochi, G., Ballentine, C. A., Ingelfield, H. E., Thompson, C. V. & O'Handley, R. C. *Phys. Rev. B* **53,** 1729–1732 (1996).
7. Chappert, C. *et al. Science* **280,** 1919–1922 (1998).

Competing financial interests: declared none.

COMMUNICATIONS ARISING

Ecology

Is coral bleaching really adaptive?

From an experiment in which corals are transplanted between two depths on a Panamanian coral reef, Baker[1] infers that bleaching may sometimes help reef corals to survive environmental change. Although Baker's results hint at further mechanisms by which reef-building corals may acclimatize to changing light conditions, we do not consider that the evidence supports his inference[1].

Baker's study attempts to test the 'adaptive bleaching hypothesis'[2] (ABH), in which stressed corals first lose their dinoflagellate symbionts (bleach) and then regain a new mix of symbionts that are better suited to the imposed stress regime[3]. Bleaching in response to increased, and not decreased, irradiance is well known[4], and Baker's corals suffered more bleaching when transferred to the shallow site. However, their mortality was lower and their mix of symbiont genotypes was altered, unlike those corals that were transplanted to the deeper site, leading Baker to conclude that the higher mortality of the latter corals was due to their failure to bleach and hence to vary their symbiont genotypes.

We are concerned not only that Baker uses undefined stresses, which do not specifically include temperature (thought to be the primary cause of mass coral bleaching[5]), but also that the corals in his treatments recover under very different conditions. The corals classified as "chronically stressed" recovered at the relatively low-light, deep-water site (20–23 m),