carbon (η^1), but also via up to five carbons (η^5), to adjust to the electronic requirement at the bonded atom (see the figure) (*12*). The same approach has already been used to prepare what is considered by some in the chemical community to be the first stable silylene (*13*). Indeed, the so-called decamethylsilicocene **3** (by analogy with ferrocene) features a divalent silicon center with a lone pair, as expected for a silylene; however, it is not dicoordinate but hypercoordinate. This compound shows the reactivity of a nucleophilic silylene because the π-bonded (η^5) Cp* ligands easily rearrange to σ-bonded (η^1) substituents. For example, it reacts with iodine (I_2) to give the tetravalent tetracoordinate adduct Cp_2SiI_2.

Along this line, the Cp^*Si^+ cation can indeed be considered as a derivative of HSi^+, but it is important to realize that the silicon is not monocoordinate but pentacoordinate; therefore, this compound is not truly electron deficient, and it even respects the octet rule. As with the silicocene **3**, its reactivity is that expected for silyliumylidenes, and it is therefore an excellent

building block for preparing a variety of silicon compounds. It is easy to imagine that, starting from such a monocoordinate compound, all the other coordination states can be reached step by step. It would be especially interesting if a wide range of Cp*-substituted silylenes (Cp*SiR) and silylium ions ($Cp^*SiR_2^+$) becomes available.

It would be a gross oversimplification to assume that the chemistry of the heavier group 14 elements (germanium, tin, and lead) resembles the chemistry of silicon. Going down the periodic table, *s*/*p* hybridization is more and more difficult, leading to what is known as the "inert *s*-pair effect," in which only the *p* electrons are used in the bonding. One of the consequences is the ease with which these elements form low-valent species. Lead even prefers to form divalent PbR_2 compounds rather than tetravalent PbR_4 compounds. Therefore, it is not surprising that the germanium, tin, and lead analogs of Cp^*Si^+ are already known (*14*). At the opposite extreme, it is difficult to imagine that Cp^*C^+ would be stable because of the reluctance

of carbon to be hypercoordinate: The carbon would be almost totally and not modestly naked, as the silicon is in Cp^*Si^+.

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PHYSICS

Only Skin Deep

William Barnes and Roy Sambles

In recent years, there has been an explosion of interest in controlling the interaction between light and matter by introducing structure on length scales equal to or smaller than the wavelength of the light involved. Functionality is thus as much a property of geometry as of material parameters—a concept sometimes referred to as metamaterials. In the 1980s, Yablonovitch (*1*) and John (*2*) showed that by introducing three-dimensional periodicity on the scale of the wavelength of light, one can alter how light interacts with the material, specifically by blocking the propagation of light to make photonic band gap (PBG) materials. More recently, by introducing structure smaller than the wavelength of light involved, synthetic "left-handed" materials have been created that have the fascinating property of negative refraction (*3*). Pendry *et al.* now show on page 847 of this issue how in theory we may be able to exploit another aspect of structure on the subwavelength scale, this time to create a new family of surface electromagnetic modes (*4*).

Wavelength-scale periodic structures with even a very small refractive index contrast may lead to the strong selective reflection of light and photonic stop-bands. However, producing a truly three-dimensional PBG material that reflects over a range of wavelengths for all directions is very challenging. Indeed,

practical applications of the PBG idea have been most fruitfully pursued in restricted dimensions, notably in the photonic crystal fiber and in two-dimensional planar slabs. An interesting variant is to apply the same idea to surface waves. In 1996 our group demonstrated that a full PBG for surface plasmon-polariton (SPP) modes could be made by introducing periodic texture into the metallic surface that supports SPPs (*5*). In the latest development by Pendry *et al.* (*4*), surface structure is used not just to control surface modes but also to create them.
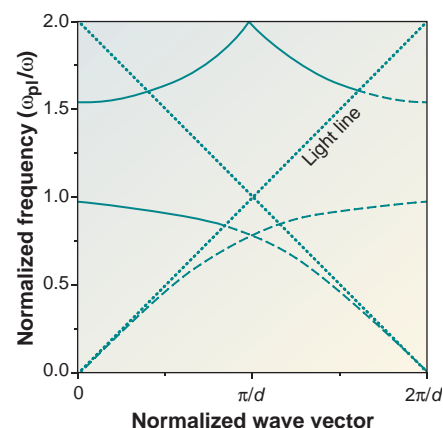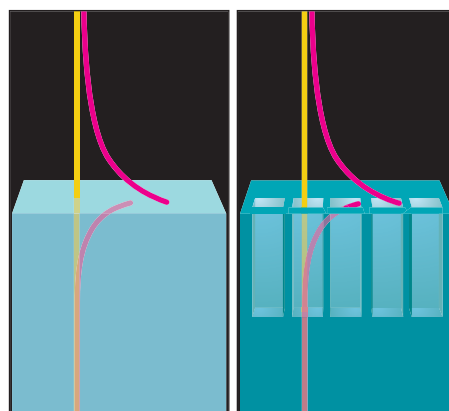
Metamaterials create surface modes. Typical surface plasmon-polariton modes have enhanced fields at the interface between a metal and a dielectric, with the fields decaying away exponentially with distance from the interface (**left**). At microwave frequencies, the penetration of the field into the metal is very small, and an effective penetration depth is achieved by introducing subwavelength holes into the surface that allow an exponential field to exist (**center**). The dispersion of these modes, including scattering attributable to the periodic nature of the holes, is shown (**right**) for a hole/period ratio (*a/d*) of 0.95. For this hole/period ratio there is a band gap just above the newly created surface plasmon frequency ω_{pl}. Nonradiative regions are shown as dashed curves.

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SPPs are surface modes that propagate at metal-dielectric interfaces and constitute an electromagnetic field coupled to oscillations of the conduction electrons at the metal surface. The fields associated with the SPP are enhanced at the surface and decay exponentially into the media on either side of the interface. In the visible domain, there is a very short penetration depth of the field into the metal and a relatively short penetration depth into the dielectric, thus allowing one to concentrate light on a scale much smaller than the wavelength involved (6). In the microwave regime, metals have a very large complex refractive index ($n + ik$), where n and k are the real and imaginary parts, respectively, and $-n \sim k \sim 10^3$. The SPP mode is then very nearly a plane wave that extends huge distances into the dielectric but only very short distances into the metal. Metals in the microwave domain are therefore frequently treated as ideal conductors, thus reflecting microwaves perfectly, which limits the usefulness of applying near-field concepts being developed in the visible domain to the microwave regime. What Pendry et al. have shown is that by puncturing the metal surface with subwavelength holes, some of the field may penetrate the (effective) surface. This changes the field-matching situation at the bounding surface and leads to a new effective surface plasmon resonance frequency. Note that this frequency is given by the geometry of the surface and may there-fore be chosen anywhere within the microwave spectrum.

This idea uses the fact that the holes (which cannot be slits) in the metal are hollow metallic waveguides and therefore have a cutoff frequency, a frequency below which no propagating modes in the guide are allowed and any incident fields fall off exponentially with distance down the hole. Below the cutoff frequency of the holes, only an evanescent field exists on the metal side of the interface, but it is just this kind of field that is required for a surface mode (see the figure, center). In this way it is now possible, the authors suggest, to design and synthesize a surface with particular surface mode properties.

Many intriguing questions are opened up when one explores the consequences of this approach. The right side of the figure is an extended dispersion diagram (with the influence of the periodicity d included) of the surface modes given by Pendry et al. in their figure 2, with the square holes having size a. For the hole/spacing ratio chosen ($a/d = 0.95$), the normalized resonant frequency is 1/0.95. It is apparent that by virtue of scattering from the periodic structure, there is a frequency region in which these new modes are above the light line and are thus radiative; it should therefore be possible to observe these modes in reflectivity experiments, assuming the relevant coupling conditions can be met. Further, for frequencies below the point where the scattered mode crosses the light line (normalized frequencies below 0.92 for the system in the figure), the modes will be delta functions (and thus unobservable) unless one allows some finite conductivity for the metal and/or fills the holes with a dielectric having some absorption (a power loss channel is required). We can also see that there now exists the possibility of scattered modes interacting and possibly forming band gaps at the Brillouin zone boundary, adding further richness to the modes supported by such a structure.

In the past few years, metamaterials have shown how new functionality can be provided and new physics explored when we start to design materials at the subwavelength level—for example, through the construction of "left-handed" materials displaying negative refraction. The idea put forward here by Pendry et al. appears to extend our repertoire of new photonic materials. This heralds a very exciting future for research in electromagnetic surfaces using waves that are only skin deep.

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IMMUNOLOGY

NK Cells Lose Their Inhibition

Peter Parham

Hepatitis C virus (HCV) is quietly colonizing the vast, plentiful archipelago that we call the human species (1, 2). For those infected, the immediate effects are mild and attract little attention. The evidence of infection is obtained only later, either in the form of virus-specific immunity or liver disease. About 20% of infected individuals clear the virus. For the rest—now numbering ~180 million persons worldwide—the infection and its accompanying immune reactions persist for decades and can lead to liver cancer or liver failure. There is no vaccine for HCV, but for those on the chase, it helps to know what factors distinguish a successful immune response from one that just blunders around. One such

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factor is a forceful cytotoxic T cell response aimed at viral peptides presented by a range of HLA class I molecules expressed by immune cells and many other cell types (3, 4). On page 872 of this issue, Khakoo et al. (5) report that another function of HLA class I molecules—the regulation of a type of immune cell called a natural killer (NK) cell—may also influence the fate of HCV infection.

NK cells are the lymphocytes that secrete cytokines and kill infected cells at early stages of a primary viral infection. Such speed is possible because NK cells abound in blood as differentiated effectors that are ready to go. On entering infected tissue, NK cells are activated by antigen-presenting cells called dendritic cells through surface receptors that sense microbial products or cellular stress (6). In contrast, in healthy tissue the activation pathways are kept in check by signals coming from inhibitory receptors (see the figure). In NK cells, this control is mediated by one or more inhibitory receptors that recognize self HLA class I molecules. Such inhibitory receptors include CD94:NKG2A, which binds to HLA-E, and certain members of the killer-cell immunoglobulin-like receptor (KIR) family, which bind to HLA-A, -B, or –C. Whereas CD94:NKG2A and HLA-E are conserved, HLA-A, B, C, and their corresponding KIR receptors are highly polymorphic (7). This variability and their functional interactions imbue KIR and HLA class I molecules with considerable potential as biomarkers of disease progression.

With this objective, Khakoo et al. determined the KIR and HLA genotypes of 1037 individuals, who were exposed to HCV and had raised a virus-specific immune response. Comparison of the 352 individuals who resolved infection to the 685 with persisting HCV revealed a difference in the distribution of HLA-C ligands and their inhibitory KIR2DL receptors. The HLA-C locus encodes two forms of KIR2DL ligand defined by the presence of either asparagine (HLA-C1) or lysine