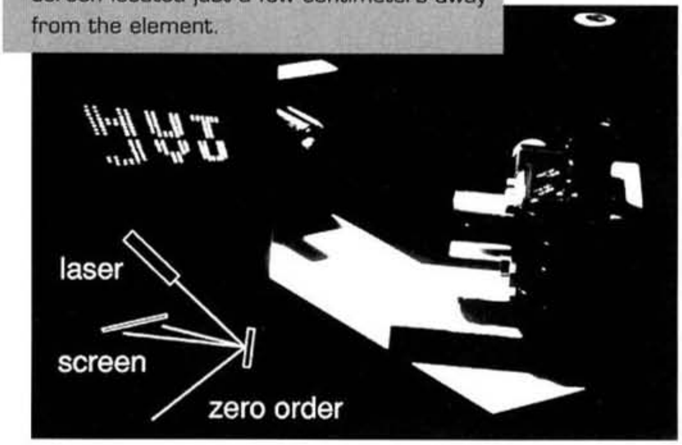
this condition is easily violated, leading to difficulties in the interpretation of experimental results. Therefore, predicting the limits of paraxial designs by rigorous electromagnetic diffraction theory is currently one of the most important topics in diffractive optics research.

We have taken some first steps to extend the scope of electromagnetic diffraction theory to the solution of the synthesis problem in the resonance domain, where the diffractive element contains wavelength-scale transverse features. Fully rigorous synthesis methods are formulated and applied to the design of periodic scatterers with one-dimensional far-field signals.[2] This approach is fruitful in the synthesis of diffractive multiple-beamsplitters and polarization-control devices for micro-optics. However, if the period of a three-dimensional scatterer is much greater than λ, or if the scatterer is non-periodic, computational constraints limit the usefulness of this approach. Therefore, we have sought methods of using the electromagnetic theory in an approximate manner.[3,4]

If the optical function of the diffractive element can be determined by geometrical considerations and the element can be treated locally as a regular resonance-domain grating (*e.g.*, high-numerical-aperture diffractive lenses), electromagnetic synthesis methods may be applied locally to optimize diffraction efficiency, thus correcting the deterioration due to failure of the paraxial approach.[3] On the other hand, we may use a resonance-domain grating, optimized by rigorous electromagnetic theory, as a carrier to encode paraxially designed diffractive elements with unrestricted phase profiles.[4] Theoretically, this hybrid scheme permits efficiencies of 80-100% with binary profiles, as well as polarization control. The figure (above right) represents an extension of the latter method to two-dimensional signals. The reflection-type ultrahigh-carrier (period 700 nm) element with a 350 × 350 μm^2 aperture was fabricated by electron-beam lithography at University of Jyväskylä, Finland.

Pattern projection by an ultrahigh-carrier diffractive element. The element is illuminated by a focused diode laser beam, and the far-field pattern is seen on the tilted screen located just a few centimeters away from the element.



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Momentum Gaps and Laser Stability

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Gaps that appear, through resonant interactions, in the dispersion relation of a particle or guided wave have had a rich history in areas of physics ranging from the study of solids to that of guided wave phenomena. Kogelnik and Shank[1] first outlined and applied the concept to laser structures and coined the term distributed feedback (DFB) to describe lasing near a Bragg resonance. DFB lasers have found applications in many areas of optics and optoelectronics, particularly those that require single-mode, narrow linewidth operation. Until very recently, DFB lasers were designed with a periodic refractive index and nearly uniform gain, resulting in frequency (or energy) gaps in the dispersion relation governing the guided modes. In contrast, a structure having periodic gain—while maintaining a uniform index—exhibits gaps in momentum rather than energy. Such lasers (termed gain-coupled DFB lasers) have received both experimental and theoretical attention in recent years due, in part, to promises of better suppression of unwanted side modes.[2-4]

A recent report by Thomas G. Brown and Lars Olofsson (Institute of Optics, University of Rochester)[5] examined the impact of a momentum gap on the stability of a laser structure. It was found that, near threshold, both the intensity and phase of such a laser can be rendered insensitive to first order perturbations in the carrier density, provided the coupling coefficient has a suitable dependence on carrier density. The same geometry exhibits a uniform intensity distribution above threshold, and yields excellent suppression of unwanted side modes.

Resonant periodic gain is not the only way to achieve a momentum gap in a laser structure. Second-order index coupling will, under the right circumstances, exhibit a momentum gap. As illustrated in Figure 1, the forward- and

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backward-traveling waves interact through a second-order scattering process. If each guided mode interacts only with the radiation mode perpendicular to the direction of propagation (vertical axis in Fig. 1), a momentum gap will appear in its dispersion relation. Brown and Olofsson showed that, if the coupling strength of counterpropagating waves has a prescribed dependence on carrier density, a small perturbation in carrier density will not perturb the output of the laser. This small-signal perturbation plays a primary role in reflection-induced intensity noise, modulation-induced frequency chirp, and noise due to reflections and instabilities. The effect that the removal of the small-signal perturbation has on the properties of such a laser, including the most fundamental aspects of laser coherence and quantum fluctuations, should be a fruitful area of future research.

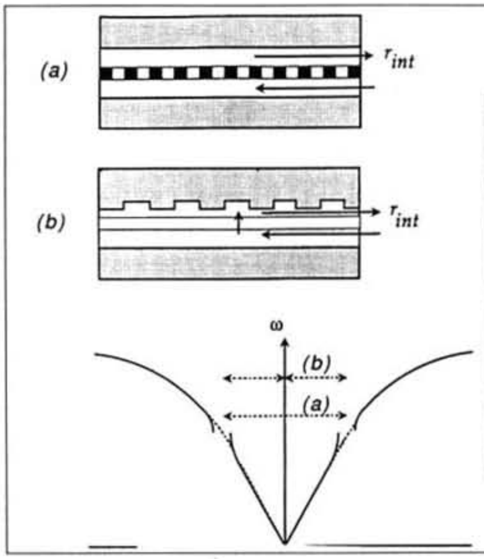

Figure 1. Momentum gaps in the dispersion relation of a periodic structure can appear through **(a)** pure gain modulation or, **(b)** through a second order index modulation.

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PROBES AND SENSORS

Optical Detection of Atoms Near Surfaces

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Since the advent of lasers in the field of atomic or molecular spectroscopy, the investigation of small concentrations of particles a few Angstroms apart from metallic or dielectric surfaces has been a challenge. We have developed a new laser-based method that combines two-photon high-resolution spectroscopy with organized monolayer film growth on planar (≤ λ/1000) surfaces. Layers of organized fatty acid films are prepared on epitaxially grown metal films on mica, and atoms adsorbed on top of the fatty acid films are examined spectroscopically in an ultrahigh vacuum (UHV), $p_0 \leq 10^{-10}$ mbar, environment.

Working in the UHV avoids contamination of the substrates with unwanted admolecules. The fatty acid mono- or multilayers contain hydrophilic headgroups (chemically bound to the surface), hydrocarbon chains of variable length between 12 and 30 Å, and hydrophobic endgroups (which form an inert surface a few Angstroms distant from the metal surface). Sodium atoms are deposited on top of those layers and are excited from the 3S state via the 3P to the 5S state in a Doppler-free arrangement using two counterpropagating single-mode ring-dye lasers. The resulting 4P→3S UV photons are observed with a photomultiplier background-free as a measure of atomic density and spectral response.

This two-photon method has been used to investigate diffusion and energy transfer of optically excited atoms to metallic surfaces on top of single[1] or multiple[2] spacer layers via a change of electronic lifetime or transition frequency. The method has been applied also to the spectroscopic investigation of atoms bound to dielectric surfaces. Here, cluster formation and laser-induced desorption of atoms from the surfaces can be investigated. Moreover, the influence of the laser radiation itself on the supporting surface (*e.g.*, heating, melting, and the corresponding phase transitions) can be observed in unprecedented detail directly on the surface by using the atoms as probe particles. Thus, besides its importance in fundamental research we anticipate applications of this laser-based technique in direct "on-the surface" investigations of laser material processing as well as in gaining new insights into thermal and optical properties of insulators, semiconductors and metals.

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