unidirectionality of the traveling wave supported by the unstable ring resonator, the temporal and spatial development of a particular phase or amplitude perturbation introduced at one point can be monitored experimentally and theoretically as the mode propagates within the resonator. Phase and amplitude perturbations of the propagating mode were introduced by using intracavity deformable mirrors and spatial masks and by injecting power from an external laser along the axis of the unstable resonator. Intracavity spatial filtering, contoured mirrors, and other forms of optical processing were shown to be viable means of compensating for the deleterious effects of the intracavity perturbations.

Intracavity spatial filters were particularly effective in suppressing undesirable resonator modes as well as improving the far-field intensity distribution. Experimental data comparing the perturbed and the corrected near- and far-field modes are presented. Analytical expressions are derived that describe the changes in the traveling-wave mode volumes and their respective resonator losses caused by the diffraction from the intracavity apertures. These expressions are found to compare favorably with experimental data.

The introduction of an external laser signal along the axis of an unstable resonator is an effective means of achieving wavelength discrimination in a multiwavelength laser. Diffractive spreading of an injected laser beam along the axis of the unstable resonator in conjunction with the geometric magnification of the resonator allows the input signal of the external laser to effectively couple to the entire unstable resonator mode volume. Experimental data is presented demonstrating the manner in which this type of perturbation propagates within the resonator and influences the lasing transitions.

Various output coupling schemes, that selectively perturb the spatial properties of the intracavity mode, were investigated as means of enhancing the integrated far-field intensity. Experimental data exhibiting substantially higher far-field irradiance than achievable with conventional coupling are presented.

In summary, the application of selective amplitude and phase perturbations is demonstrated as an effective means of compensating for the deleterious contributions introduced by the gain medium, suppressing undesirable resonator modes and laser transitions, and achieving near diffraction-limited beam quality.

X.5 A Multi-Mode Approach to the Physics of Unstable Resonators, H. Shih and Marlan O. Scully, *Department of Physics and Optical Sciences Center, University of Arizona, Tucson, Arizona 85721*, and P. V. Avizonis, *Air Force Weapons Laboratory, Kirtland AFB, New Mexico 87117.*

By inserting an appropriate diverging lens into a stable resonator, we are able to consider the "modes" of an unstable resonator as a mixture of the well known stable resonator modes. The effect of finite mirror-size is accounted for in our model by assuming the presence of a properly distributed absorbing medium. Unlike much of the previous work on unstable resonator systems, the effects of the active lasing medium are naturally included in our approach.

With the electric field playing the role of a state vector and the stable modes the roles of basis functions, our working equation is very similar to the Heisenberg matrix formulation of quantum mechanics.

Symmetry considerations enable us to reduce a complicated three-dimensional problem to a much simpler one-dimensional "linear-chain" problem, which we are able to solve analytically in the asymptotic limit. Our asymptotic theory predicts the behavoir of the lowest-loss resonant modes in an unstable resonator and is supported by numerical computations.

In the stable-unstable transition region, as well as in the unstable region, the lowest-order mode pattern retains its Gaussian form when losses are included (to account for finite mirrors). Without losses, the beam width diverges as the transition point (point at which the system goes from stable to unstable) is approached from the stable region. With loss included, the beam width remains finite.

We find the following physical picture for the stable-unstable transition useful: We regard the modes in any resonator, stable or unstable, as mixings of the known modes of some appropriately chosen stable resonator. Let the projection of the unstable resonator mode in question into the l-th mode of the appropriate stable resonator be given by A_l. We then represent A_l by a "spin" on the l-th site of a straight line with equal distance separating the neighbors. The spins are free to rotate in the plane perpendicular to the line when the interaction between modes is turned off. When the interaction (which involves nearest neighbors only) is turned on, the "spins" will couple as in a linear chain and behave cooperatively. In the stable region there exists only short range order and this described by a small "correlation length." On the other hand, long-range order (involving a large number of "spins") occurs near the transition point (marginal stability), and an anti-ferromagnetic type of ordering with neighboring spins aligned anti-parallel occurs. The effect of diffraction-loss is to render the correlation-length finite and to cause a "twist" of the spins, relative to one another, all the way down the linear chain. In the limit of very severe unstability, a ferromagnetic-type of ordering with all spins aligned results.

X.6 Gain Induced Stability of Active Plane-Parallel Resonators, W. J. Witteman and G. J. Ernst, *Twente University of Technology, Enschede, The Netherlands.*

Previously[1] we showed that a stable resonator, i.e., a system that is not subject to the type of loss which can be predicted by geometrical optics alone, can always be obtained if any quadratic gain profile is present. This can be found for any set of curved and/or flat mirrors. Experimental studies[2] with a plane-parallel xenon laser having a profile with the highest gain at the center have shown that confined beams are possible. It is, however, also possible to obtain stable oscillations in a plane-parallel resonator with a medium having a profile with the lowest gain at the centre. Although one might expect at first glance that such a medium would tend to broaden the beam diameter indefinitely, it turns out that for such a medium the wave front converges and, hence, a limited confined beam is obtained nevertheless. This, indeed, can be observed with a plane-parallel resonator and a saturated medium. Saturation of the medium by the lowest order mode causes the gain to increase with the distance from the axis. The experiments have been done with a sealed-off plane-parallel CO_2 laser of one meter length and an internal diameter of 20 mm. Without gain variations such a system is unstable because of thermal defocussing by the heated gas. But due to sufficient high gain variation the beam converges nevertheless. Since the gain variation increases with decreasing reflectivity confined beams near the optical axis are only observed at sufficient low reflectivity. The experiments were done with one totally reflecting mirror and an outcoupling mirror having reflectivity of respectively 90, 80, 50 and 36%. Using a high reflectivity of 90 or 80% the outcoupling beam is mainly concentrated near the edge with irregular density distributions which are difficult to define, even at a low excitation rate. On the other hand, for a low reflectivity of 50 or 36% the beam is radially symmetric, concentrated near the axis having decreasing intensity with the distance from the axis. The central part of these intensity profiles can be quite well described by a Gaussian distribution.

The experimental behaviour can be understood by an analysis in which the main quadratic terms of the variation of the propagation constant near the optical axis due to gain variations, dispersion and heat effects are taken into account. It will be shown that in spite of the thermal defocussing stable oscillations can be obtained as long as these thermal effects are below a certain limit given by gain variations. The described effect can be best demonstrated with a cavity of about one meter length.

Furthermore, it is found that due to the convergence of the wave front the radial radiation transport[3] at the optical axis is equal to the radiation gained directly from the medium, independent of thermal lensing. This explains why a sealed-off CO_2 laser of one meter length having an outcoupling mirror of only 50% operates with an output performance of 23 watts and an efficiency of 12%.

[1] G. J. Ernst and W. J. Witteman, *IEEE J. of Quantum Electronics*, vol. QE-9, p. 911, 1973.

[2] L. Casperson and A. Yariv, *Appl. Phys. Letters*, vol. 12, p. 355, 1968.

[3] G. J. Ernst and W. J. Witteman, *IEEE J. of Quantum Electronics*, Jan. 1974.