Coherent operation of an array of diode lasers using a spatial filter in a Talbot cavity

F. X. D'Amato, E. T. Siebert, and C. Roychoudhuri
Perkin–Elmer Corporation, 100 Wooster Heights Road, Danbury, Connecticut 06810

(Received 19 January 1989; accepted for publication 19 June 1989)

Coherent operation of an array of AlGaAs diode lasers was obtained by placing the array in an external cavity which made use of the Talbot self-imaging effect to couple the laser diodes together. A spatial filter was required to suppress oscillation of the highest order mode of the array. This filter introduced no significant loss to the cavity mode, and the mode was observed to be stable up to the maximum rated drive current for the device.

Several authors have reported phase locking of small numbers of laser diodes by placing a diode array in an external cavity and using a spatial filter placed in a Fourier transform plane of the array[1–3] to force mutual coherence between elements of the array. This technique works well for relatively small arrays, but becomes impractical for large scale arrays. Recently, an external-cavity technique has been demonstrated which takes advantage of the Talbot self-imaging effect[4] to phase lock an array of laser oscillators.[5–9] A significant advantage of the Talbot cavity as opposed to other external cavity approaches to phase-locking laser arrays is that the Talbot cavity can be scaled up to accommodate arrays containing a large number of lasers if attention is paid to control of the oscillating modes of the array. In this letter we demonstrate how the mode of a laser diode array can be controlled in a Talbot cavity using an intracavity spatial filter.

The Talbot cavity consists of a flat mirror placed a distance D^2/λ from an array of lasers (lasers separated by a distance D and oscillating at wavelength λ). Analysis of the modes of the Talbot cavity indicates that, in general, more than one array mode can oscillate within the cavity. Figure 1 shows the effective level of cavity feedback (as defined by the solutions of the eigenvalue equation in Ref. 6) for the modes of a 30-element array of laser diodes for which the ratio of diode separation to diode width parameter is 10:1. In this case the lowest order mode of the array (in which all the diodes oscillate in phase) and the highest order array mode (adjacent diodes oscillate 180° out of phase) have the same level of feedback from the external cavity; the external cavity is not able to discriminate between the two modes.

To control the mode of a laser array in a Talbot cavity a spatial filter must be placed in the cavity to suppress oscillation of the highest order array mode. Figure 2 illustrates how the filter works. When the array is in either its lowest or highest order mode, an image of the array is formed at the mirror of the Talbot cavity. In the highest order mode, these images are aligned with respect to the sources; in the lowest order mode the images are offset with respect to the sources by a distance $D/2$. If the images are well resolved a spatial filter placed in front of the mirror as shown in Fig. 2 will suppress the highest order mode of the array, while introducing little loss to lowest order mode. In order for the images to be well resolved at the mirror plane the effective fill factor for the cavity mode in the output plane must be less than one, which would lead to a multilobed far field for the mode. However, aperture filling optics can be introduced

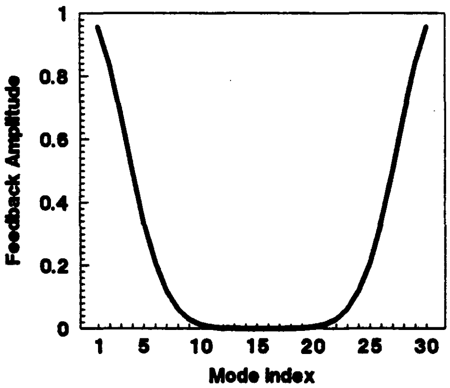

FIG. 1. Effective level of cavity feedback for the modes of a 30-element diode array in a Talbot cavity with no spatial filter. Ratio of source separation to source width is 10:1 for this calculation.

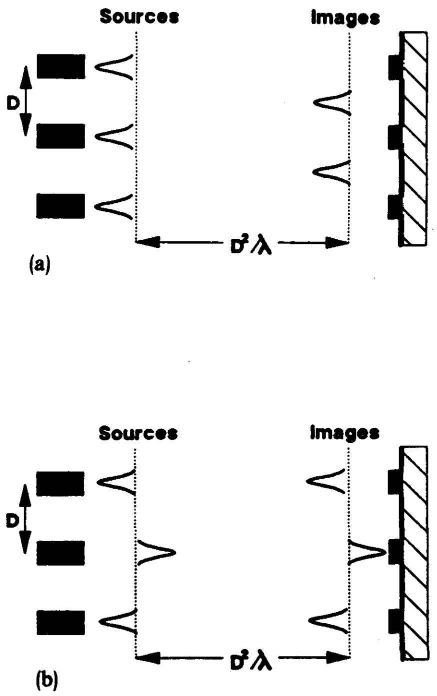

FIG. 2. Effect of a spatial filter on the modes of a Talbot cavity. (a) The lowest order mode of the cavity is unaffected by the filter; (b) the filter introduces loss into the highest order cavity mode.

 0003-6951/89/350816-03$01.00

external to the cavity to produce a single-lobed far field without altering the oscillating mode of the cavity.

Figure 3 shows a schematic of the apparatus used to demonstrate mode control in a Talbot cavity. The laser array used for this work was a 30-element linear array of index-guided AlGaAs lasers manufactured by General Optronics. The elements of the array were antireflection (AR) coated and had residual front-facet reflectivity of roughly 3%. These diodes were not coupled together on the chip and were observed to oscillate incoherently in the absence of external feedback. Since the lasers were spaced too close to each other on the chip to allow construction of a simple Talbot cavity for the array, a lens system consisting of a 0.6 N.A. wide-field magnifying lens and a field lens was used to create a flat image of the array at a 38$\times$ magnification. This image consisted of 30 elements at 380 μm separation, each element having a Gaussian width parameter of 38 μm. The magnified image of the diode array acts as the effective source for the Talbot cavity. The Talbot cavity consisted of a 40 mm focal length AR-coated cylindrical lens (needed to control divergence of the beam perpendicular to the array junction plane) and a flat mirror 167 mm from the effective source array. Aperture filling lenslets were not used in this work, since they were not required to control the divergence of the effective sources in the plane of the array and would have introduced unnecessary losses in the cavity. The spatial filter consisted of a chrome film that had 180-μm-wide clear apertures etched on 380 μm centers; the film was supported on an optically flat AR-coated fused silica plate. The spatial filter plate was tilted slightly out of the array junction plane in order to prevent residual reflections from the chrome film from coupling back into the cavity mode.

Figure 4(a) shows the far-field pattern emitted by the diode array in the Talbot cavity with a spatial filter placed in the cavity. The position and magnitudes of the lobes in the far-field pattern agree well with those predicted for the lowest order mode of the array. The measured full width at half maximum for the lobes (0.23 mrad) was approximately three times the diffraction limit for the array, indicating that not all of the diodes were completely locked to the fundamental cavity mode. The broad base beneath each of the lobes is an artifact of an aberration that was present in the magnification system at the time of the experiment. Figure 4(b) shows the same far-field pattern when the spatial filter was removed. Here two separate sets of lobes were observed in the far field, corresponding to the lowest and highest order modes of the diode array. In addition to the diffractive lobes,

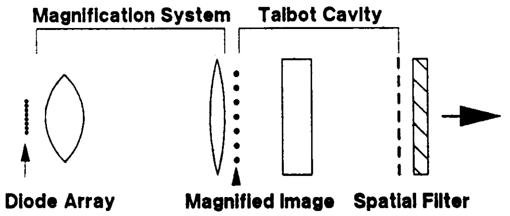

FIG. 3. Schematic of the cavity used for these measurements. The lens system creates a flat, magnified image of the diode array near field which acts as the effective source for the Talbot cavity.

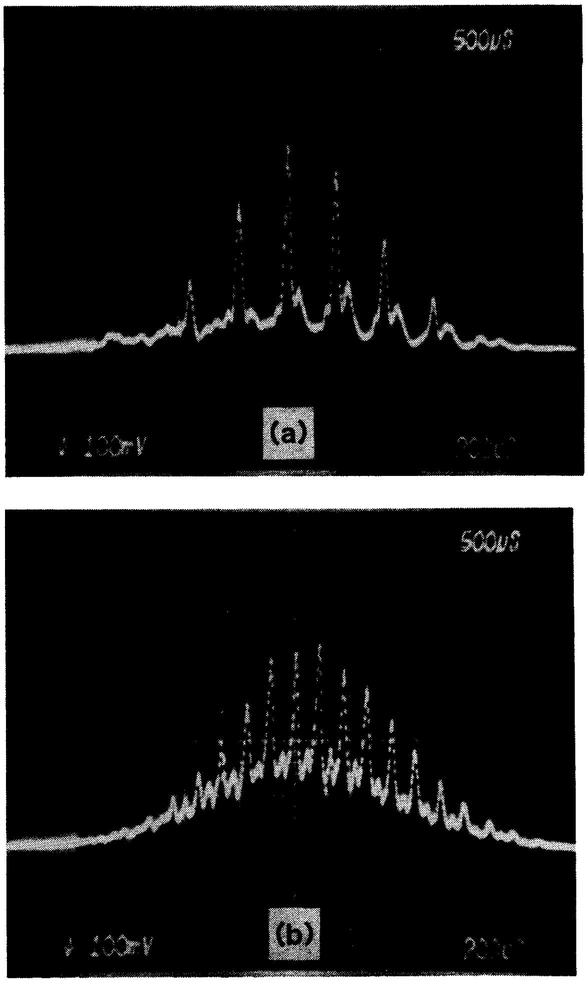

FIG. 4. (a) Far field of the 30-element diode array oscillating in its fundamental mode in a Talbot cavity with a spatial filter. (b) Far field of the 30-element diode array in a Talbot cavity with no spatial filter. The array oscillated in its lowest and highest order modes simultaneously.

70% of the power in the far field appears in a broad background that corresponds diodes that were not locked to a cavity mode. This suggests that the degree of coherence of cavity output was limited by diodes that were not locked to the modes of the external cavity (due to a limited degree of external feedback), rather than simultaneous oscillation of the array as a whole in several low-order modes of the external cavity. Failure of the device prevented a complete measurement of the degree of mutual coherence between individual diodes to reconcile the difference.

The threshold current for the diode array with no feedback was 1.35 A; when the array was coupled to the external cavity with no spatial filter, threshold dropped to 1.28 A. When the spatial filter was inserted into the cavity, the threshold current remained at 1.28 A, indicating that the spatial filter did not introduce any significant loss into the lowest order array mode. The positions and widths of the diffractive lobes did not change up to a bias current of 1.8 A, which was the thermal limit for device operation as indicated by thermal saturation of the power versus current curve for the device.

This work was supported by the Department of the Air Force.

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