# Stitching Error Reduction in Electron Beam Written Gratings

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**Abstract:**. A multiple-write electron beam lithography technique is described as a linear filter on the grating spatial frequency spectrum. Experimental observation of optical diffraction patterns show a 25 dB reduction in stitching error side modes.

**OCIS codes:** (050.1950) Diffraction Gratings; (140.5960) Semiconductor Lasers

### Summary

Electron beam lithography offers sub-micron resolution necessary for first order diffraction gratings as well as flexibility to implement non-uniform gratings designs $\lambda/4$ phase shifts, corrugation pitch modulation (CPM)[1], and chirp[2]. Sample warping or tilt can cause miscalibration between the stage and beam movements resulting in interruptions at the end of each electron beam field. These systematic stitching errors scatter waves which add coherently and can dramatically affect DFB lasers. Figure 1 shows the formation of satellite stop-bands in the below-threshold luminescence spectrum of a DFB laser due to stitching error.

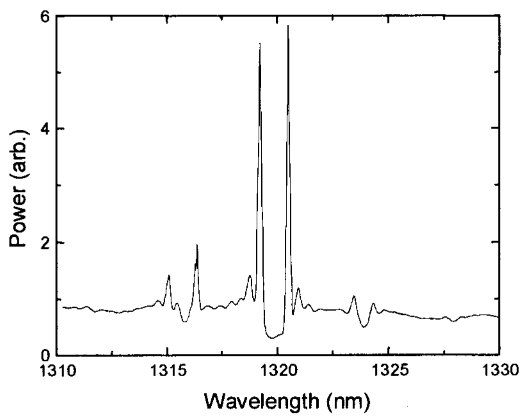


Fig. 1. Sidebands in below threshold DFB spectrum due to stitching error.

Multiple-write techniques have been used previously to reduce stitching errors [2,3]. The method of reference 2 moves the stage every 1/3 of a field and writes 1/3 of the total exposure. Essentially, this process, called shot-shifting from here on for brevity, results in the error being absorbed into every grating tooth to form a uniform grating but with altered duty-cycle[2]. This explanation does not provide a complete description of the grating spatial frequency spectrum and does not quantify the amount of side-mode reduction that is possible.

Considering only first-order diffraction, the spectrum of an infinite grating written with field size L, pitch T, and stitching error $\Delta x$ can be expressed as a product of two factors as

$$G(k) = G_L(k)S(k) = [\mathrm{sinc}((k-K_T)L/2) - \mathrm{sinc}((k+K_T)L/2)]\sum_{n=-\infty}^{\infty}\delta(k-2\pi n/L'). \qquad (1)$$

Here, $L'=L+\Delta x$. The first factor represents the spectrum of a single field of the grating and is peaked at $K_T=2\pi/T$. The second factor is the result of repeating the sections. When $\Delta x=0$, the delta functions align with the peaks and zeros of $G_L(k)$ corresponding to an infinite sinusoidal grating. When $\Delta x\neq 0$, the delta functions move off the zeros giving rise to multiple sidebands spaced by the actual field wavevector $2\pi/L'$. M-order shot-shifting can be thought of as a linear filter which sums M copies of g(x) delayed by multiples of L′/M. In the spectral domain, this filter is given by

$$F_M(k) = \tfrac{1}{M}\exp\left(\tfrac{ikL'}{2}\left(1-\tfrac{1}{2M}\right)\right)\frac{\sin(kL'/2)}{\sin(kL'/2M)}. \qquad (2)$$

When the number of grating periods N=L/T is divisible by M, the main components near $\pm K_T$ are preserved while the stitching error sidebands are exactly cancelled. Note that only the nearest M-1 sidebands are nulled since $F_M(k)$ is periodic in $2\pi M/L'$.

To compare the predictions of this linear theory to the highly nonlinear grating exposure process, diffraction measurements were conducted on gratings written in PMMA on silicon substrates to quantify the actual side mode reduction achievable in practice. Figure 2 shows measured angular spectra taken from gratings with intentional stitch errors of approximately 30 nm. The top plot shows the array of sidebands generated by the stitching errors, while the lower plots show the spectral filtering of 2,3, and 5 order shot-shifting which is as predicted by Eq. 2. The maximum observed suppression in the side band diffraction efficiency was -25 dB. Suppression below –20 dB was maintained while varying the total dose by ±30% and the shot-shift order from 2 to 5.

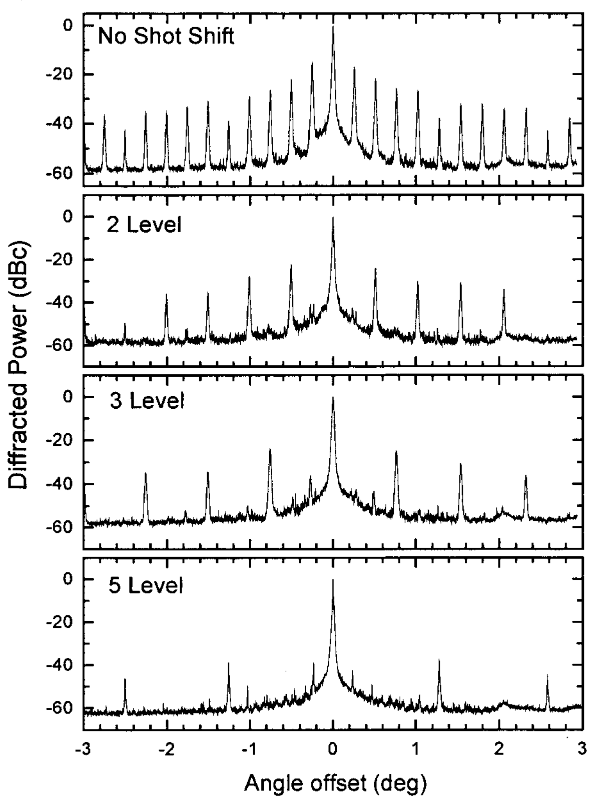


Fig. 2. Diffraction measurements of gratings with intentionally introduced stitching errors counter-acted by different orders of shot-shifting.

Figure 3 shows spectra of an array DFB lasers written with shot-shifted gratings for water detection at 1.368 μm. The small dips in the luminescence are due to water absorption lines are do not shift as the pitch is changed. No evidence of stitching sidebands is observed indicating that this is a robust process for DFB lasers. For other applications, these results should serve as a guide to determine the proper order of the shot-shift filtering and the achievable sideband suppression.

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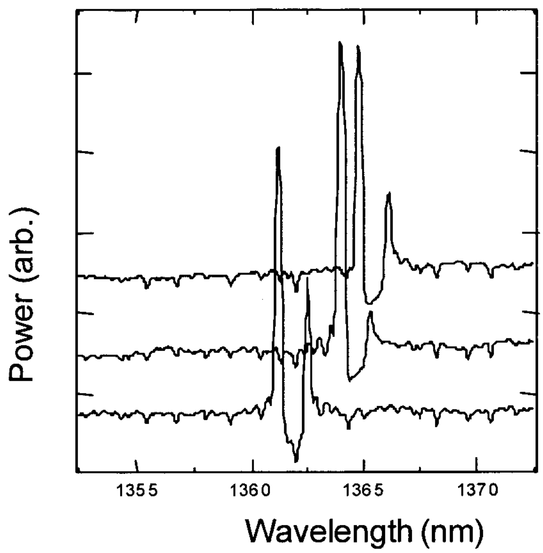


Fig. 3. Array of three DFB lasers written with shot-shifted gratings. Small dips are water absorption lines

## References

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