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Supporting information for article:

Hybrid height and slope figuring method for grazing-incidence reflective optics

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Table S1 Alternating 2-objective optimization for the slope-based method.

Input: ϵ_x^{rms}, ϵ_y^{rms}, z_x^d, z_y^d
Output: t_{opt}^{slope}
Initialization: i_{max}, t_{min}, $z_x^r = z_x^d$, $z_y^r = z_y^d$, $t_{opt}^{slope} = 0$;
while $i = 1$ **to** i_{max} **do**
    $\delta_x^{rms} = \mathrm{RMS}(z_x^r)$, $\delta_y^{rms} = \mathrm{RMS}(z_y^r)$;
    if $\delta_x^{rms} \le \epsilon_x^{rms}$ **and** $\delta_y^{rms} \le \epsilon_y^{rms}$
        break;
    else
        if $\delta_x^{rms} > \epsilon_x^{rms}$
            $t_2 = \mathrm{Optimize\_}f_2(z_x^r, b_x)$;
            $t_{opt}^{slope} = t_{opt}^{slope} + t_2$;
            $t_{opt}^{slope} = t_{opt}^{slope} - \min(t_{opt}^{slope}) + t_{min}$;
            $z_x^r = z_x^d - b_x * t_{opt}^{slope}$, $z_y^r = z_y^d - b_y * t_{opt}^{slope}$;
        end
        if $\delta_y^{rms} > \epsilon_y^{rms}$
            $t_3 = \mathrm{Optimize\_}f_3(z_y^r, b_y)$;
            $t_{opt}^{slope} = t_{opt}^{slope} + t_3$;
            $t_{opt}^{slope} = t_{opt}^{slope} - \min(t_{opt}) + t_{min}$;
            $z_x^r = z_x^d - b_x * t_{opt}^{slope}$, $z_y^r = z_y^d - b_y * t_{opt}^{slope}$;
        end
    end
end

ϵ_x^{rms}, ϵ_y^{rms}: specified RMSs of the residual slope errors; i_{max}: the max number of iterations; δ_x^{rms}, δ_y^{rms}: current RMSs of the residual slope errors; t_{min}: minimum dwell time added to each dwell point.

Table S2 Alternating 3-objective optimization algorithm for the hybrid method. The additional, height-based operations are highlighted.

Input: $\epsilon^{rms}, \epsilon_x^{rms}, \epsilon_y^{rms}, z^d, z_x^d, z_y^d$
Output: t_{opt}^{hybrid}

Initialization: $i_{max}, t_{min}, z^r = z^d, z_x^r = z_x^d, z_y^r = z_y^d, t_{opt}^{hybrid} = 0$;
while $i = 1$ **to** i_{max} **do**
  $\delta^{rms} = \mathrm{RMS}(z^r), \delta_x^{rms} = \mathrm{RMS}(z_x^r), \delta_y^{rms} = \mathrm{RMS}(z_y^r)$;
  If $\delta^{rms} < \epsilon^{rms}$ **and** $\delta_x^{rms} < \epsilon_x^{rms}$ **and** $\delta_y^{rms} < \epsilon_y^{rms}$
    break;
  else
    if $\delta^{rms} \geq \epsilon^{rms}$
      $t_1 = \mathrm{Optimize\_}f_1(z^r, b)$;
      $t_{opt}^{hybrid} = t_{opt}^{hybrid} + t_1$;
      $t_{opt}^{hybrid} = t_{opt}^{hybrid} - \min(t_{opt}^{hybrid}) + t_{min}$;
      $z^r = z^d - b * t_{opt}^{hybrid}, z_x^r = z_x^d - b_x * t_{opt}^{hybrid}, z_y^r = z_y^d - b_y * t_{opt}^{hybrid}$;
    end
    if $\delta_x^{rms} \geq \epsilon_x^{rms}$
      $t_2 = \mathrm{Optimize\_}f_2(z_x^r, b_x)$;
      $t_{opt}^{hybrid} = t_{opt}^{hybrid} + t_2$;
      $t_{opt}^{hybrid} = t_{opt}^{hybrid} - \min(t_{opt}^{hybrid}) + t_{min}$;
      $z^r = z^d - b * t_{opt}^{hybrid}, z_x^r = z_x^d - b_x * t_{opt}^{hybrid}, z_y^r = z_y^d - b_y * t_{opt}^{hybrid}$;
    end
    if $\delta_y^{rms} \geq \epsilon_y^{rms}$
      $t_3 = \mathrm{Optimize\_}f_3(z_y^r, b_y)$;
      $t_{opt}^{hybrid} = t_{opt}^{hybrid} + t_3$;
      $t_{opt}^{hybrid} = t_{opt}^{hybrid} - \min(t_{opt}^{hybrid}) + t_{min}$;
      $z^r = z^d - b * t_{opt}^{hybrid}, z_x^r = z_x^d - b_x * t_{opt}^{hybrid}, z_y^r = z_y^d - b_y * t_{opt}^{hybrid}$;
    end
  end
end

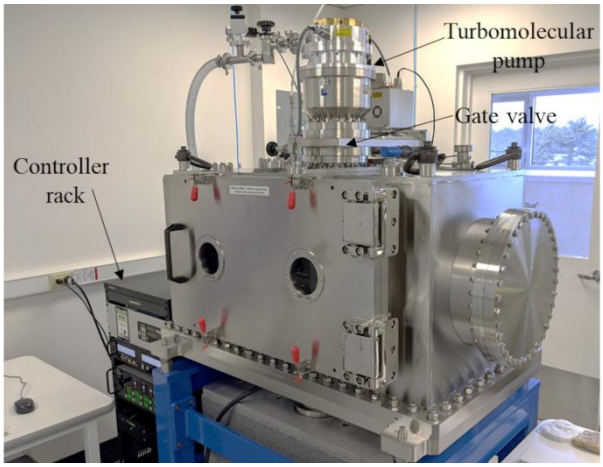

Figure S1 IBF system at NSLS-II. It is equipped with a KDC 10 ion source and an LFN 1000 neutralizer from Kaufman & Robinson Inc.

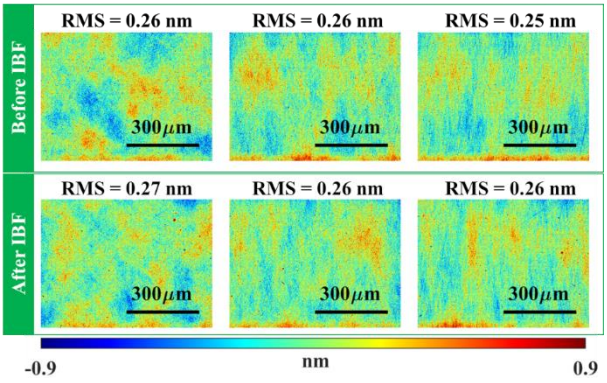

Figure S2 The micro-roughness before and after the IBF process were measured with the Zygo NewView system. The roughness was kept at the sub-0.3 nm RMS level, which demonstrated that the initial surface roughness of the mirror was already below the specification and well-maintained during the IBF process.

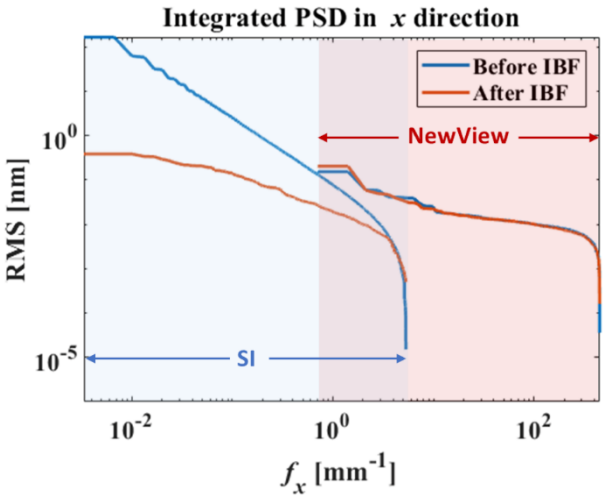

Figure S3 The integrated PSD before and after the IBF process measured with the SI and Zygo NewView systems. It can be observed that the integrated PSDs keep decreasing at spatial frequencies < 5 mm-1 during IBF, indicating that IBF is only capable of correcting the errors in low to middle frequencies and has no effect on the height-frequency components.