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Relationship between fiber center and Silicon V-groove width

Optoelectronic packaging technology is based on mounting active devices on silicon substrates which have V-grooves accurately etched in them so that when a fiber is placed in the V-groove, the core center is within ±1μm of the optical axis of the active device. This technology is based on anisotropic etches which etch the silicon [100] plane more rapidly than the [111] plane. When starting with a [100]-oriented silicon wafer that has been masked off so that only a strip of silicon surface of width $2w$ is exposed to the etch

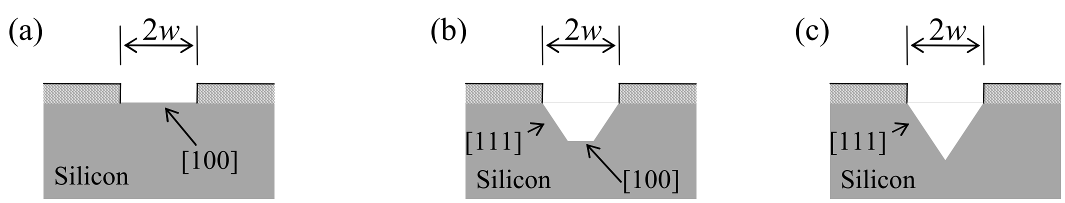

Figure 1

(figure 1a), then the silicon will etch the exposed [100] plane down more rapidly than the [111] that becomes exposed as material is removed from the [100] surface (figure 1b). Because the [111] plane makes an angle α=35.26° to the [100] surface, the etching results in a sloped edge on each side (figure 1b). If left in the etch long enough, then the two sloped edges meet to form a V-groove (figure 1c). Since no [100] surface is exposed, the etching slows greatly. This self-limiting etch feature results in the ability to accurately set the depth of the etch d by choosing $2w$ precisely. Thus, a fiber of radius R can have its center precisely placed to any point above or below the surface of the silicon (figure 2).

There are two situations that must be considered when determining the dependence of w on the required height h of the fiber core above or below the silicon surface. The first

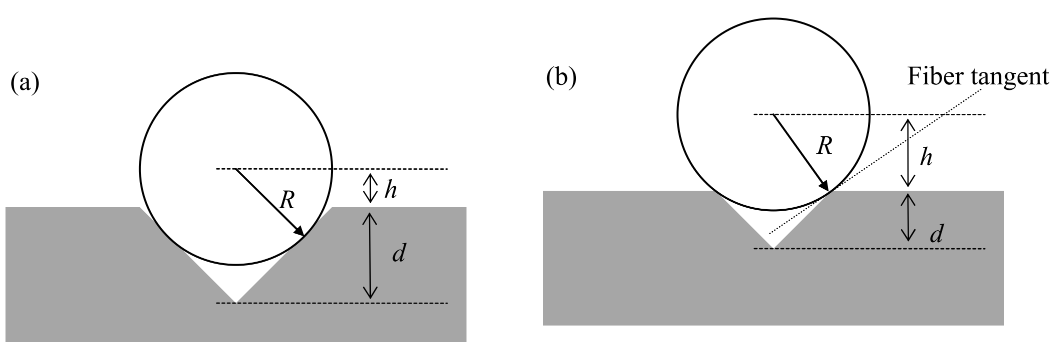

Figure 2

case is when the width of the V-groove is sufficiently large that the fiber rests deep within the V-groove (figure 2a). Then the V-groove wall is tangent to the fiber surface and there exists a radius vector of the fiber that is normal to the V-groove wall. The second case is when the V-groove width is sufficiently narrow so that the fiber rests on the two V-groove corners (figure 2b). Below we develop expressions that determine the required V-groove starting width 2w to obtain the desired fiber height h above or below the silicon surface.

Consider the case depicted in figure 2a first, drawn in more detail in figure 3. The following relationships can be determined from the figure:

$$w = x_1 + x_2$$
$$x_1 = R\cos\alpha$$
$$x_2 = y_2 \tan\alpha$$
$$y_2 = y_1 - h$$
$$y_1 = R\sin\alpha$$

Thus,

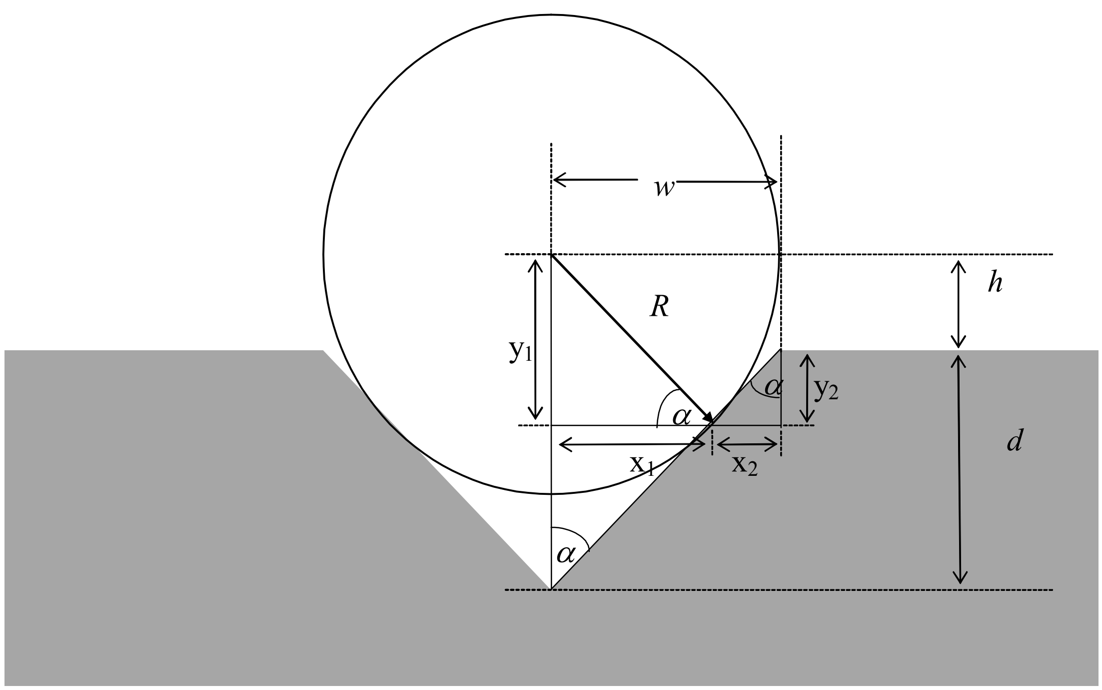

Figure 3

$$\begin{aligned} w &= R\cos\alpha + (R\sin\alpha - h)\tan\alpha \\ &= R\cos\alpha + R\frac{\sin^2\alpha}{\cos\alpha} - h\tan\alpha \\ &= \frac{R}{\cos\alpha} - h\tan\alpha \\ &= \frac{R - h\sin\alpha}{\cos\alpha} \end{aligned}$$

for $h \geq y_1 = R\sin\alpha$. The case depicted in figure 2b occurs when $h \leq y_1 = R\sin\alpha$. Then, $w = \sqrt{R^2 - h^2}$.

To summarize,

$$w = \begin{cases} \dfrac{R - h\sin\alpha}{\cos\alpha}, & h \geq R\sin\alpha \\ \sqrt{R^2 - h^2}, & h \leq R\sin\alpha \end{cases}$$

A plot of *w* versus *h* is shown in figure 4:

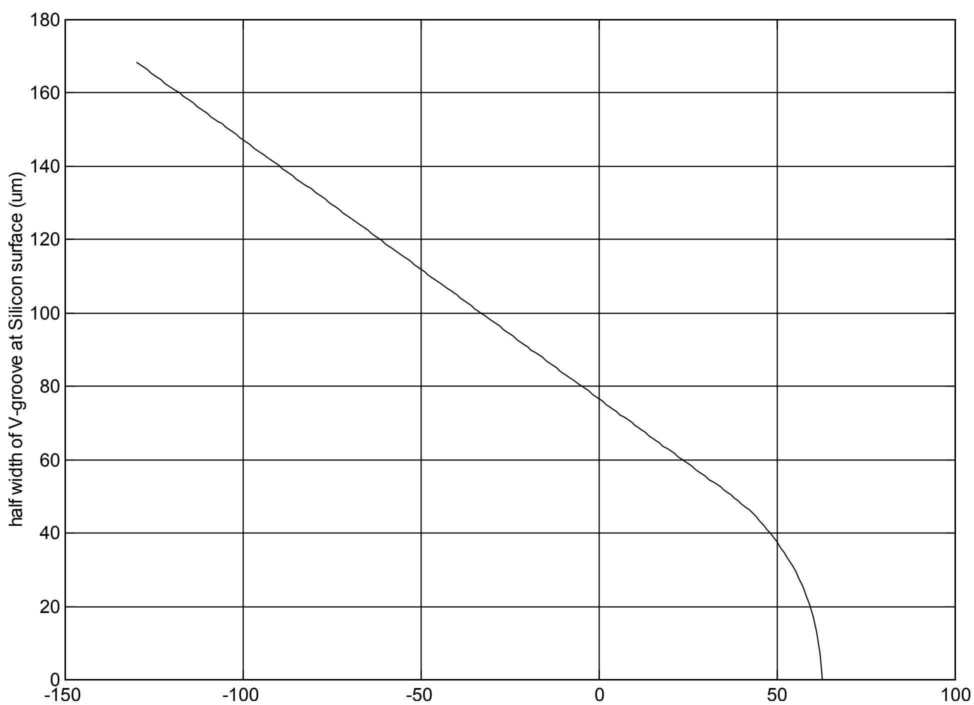

Figure 4