Stress reduction by design for ball grid array

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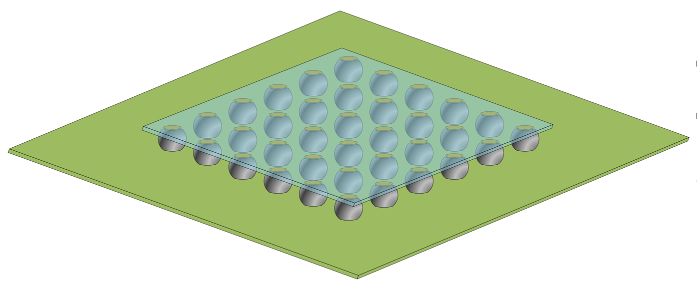
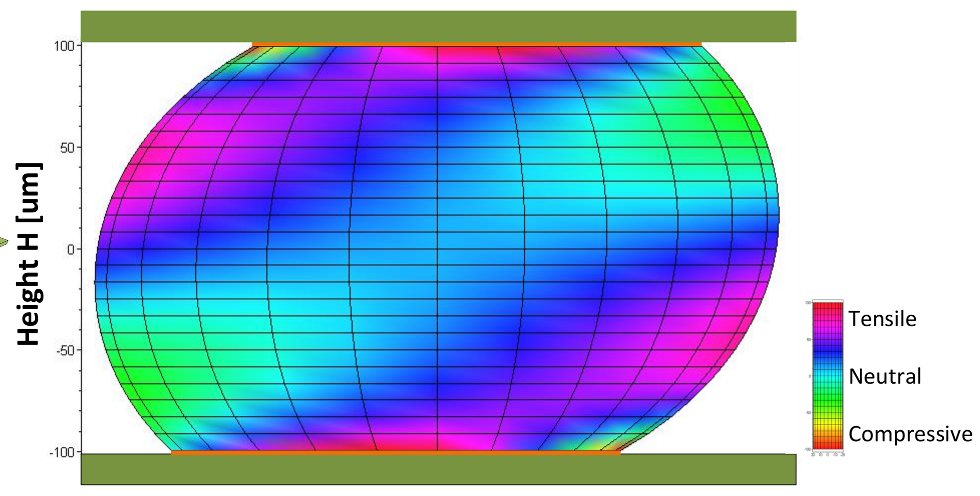
Introduction

BGAs or Ball Grid Arrays are characterized through their large array of solder ball based interconnects at the bottom side of the components.





The solder joint serves both as electrical interconnect as well as the mechanical fastener of the component to the board.

A simple model of a deflected bump can be made in case one assumes that the bump is built from shearing discs. In this way the deflection of the central axis can shown to be:

$$u(z) = \frac{1}{2}\,\frac{X\,\operatorname{arctanh}\left(\frac{z}{r_0}\right)}{\operatorname{arctanh}\left(\frac{k}{r_0}\right)}$$

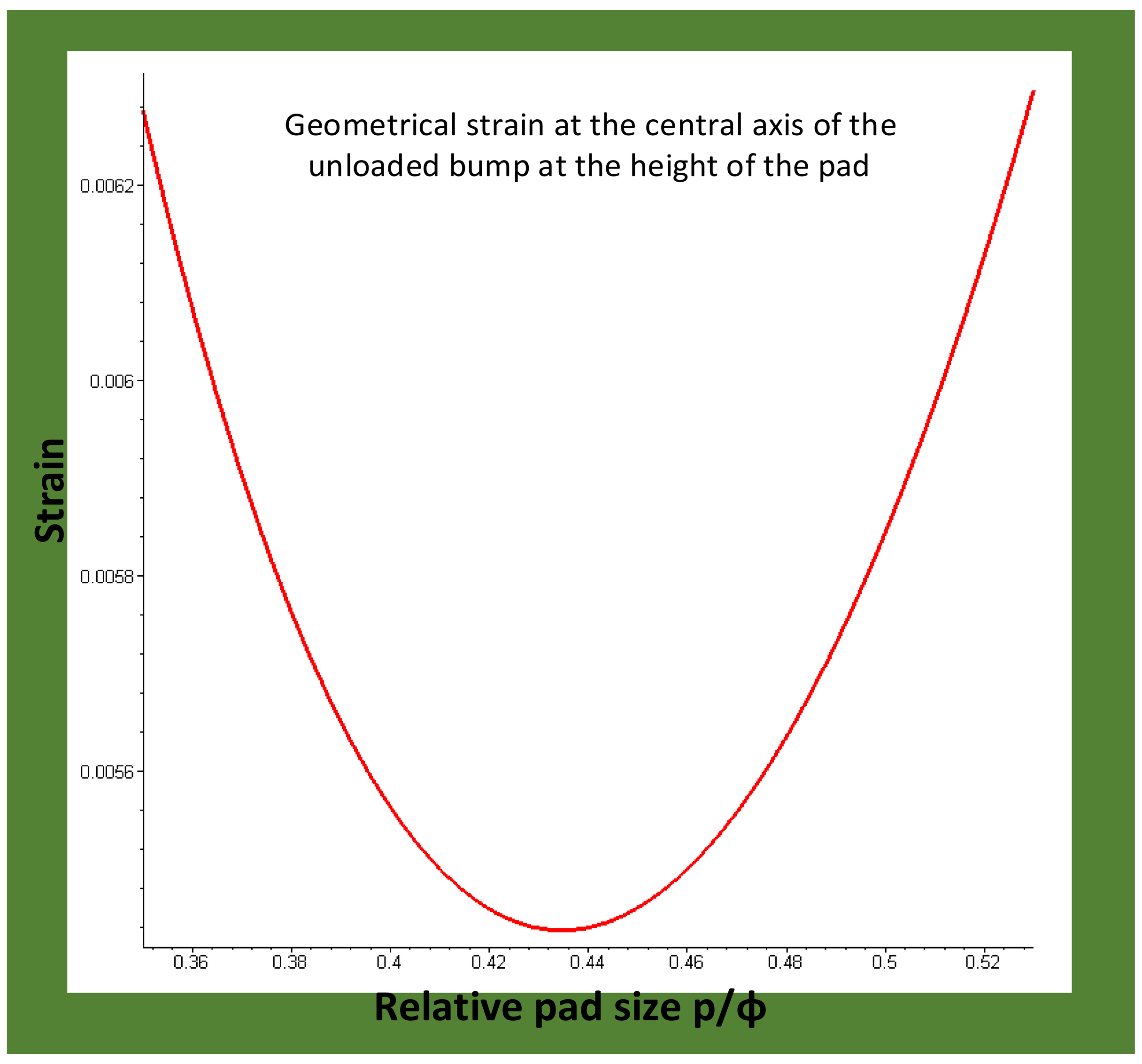
Where X is the maximum deflection between substrate and component. K depicts half the height of the unloaded bump and r_0 is the radius of the bump at the equator.

The strain *S(k)* at the pad can be estimated as:

$$S(k) = \frac{1}{2}\left(\frac{\partial\, u(z)}{\partial\, z}\right)^2_{z=k}$$

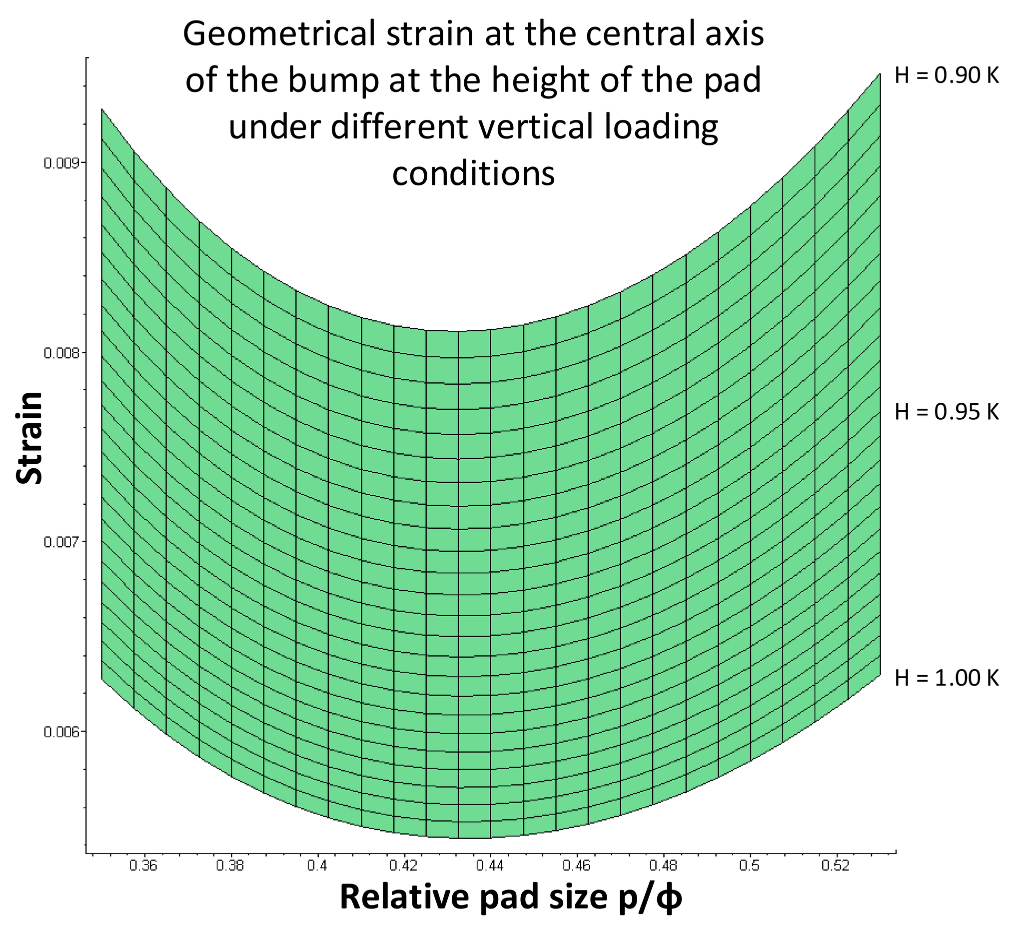
Upon applying this to the equation for *u(z)* one obtains for *S(k):*

$$S(k) = \frac{1}{8}\,\frac{X^2\,(p^2 + k^2)}{p^4\,\operatorname{arctanh}\left(\sqrt{\frac{k^2}{k^2 + p^2}}\right)^2}$$



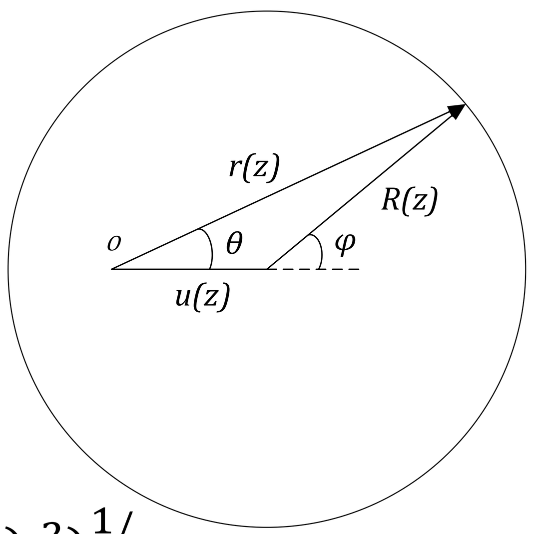
The total deflection used here is 5% of the solder ball diameter. The minimum strain is found for p/ϕ is 0.435. The offset in the vertical scale should be noted.

A graph can be made of the bump under different vertical loading conditions, i.e. bump deformation caused by weight of the component.



The weight of the component enhances the strain, but the minimum stays at the same location. Therefore the ratio of pad radius and solder ball diameter can be taken as a design rule.

The angular behavior of the strain can be estimated from the expression for the surface integral. The expression in cylindrical coordinates can be derived as follows:
The radius r(z,θ) in the laboratory coordinate system $z,\ \theta$ can be derived from the following equations:



$$r(z,\theta)\cos(\theta) = u(z) + R(z)\cos(\varphi)$$
and $r(z,\theta)\sin(\theta) = R(z)\sin(\varphi)$

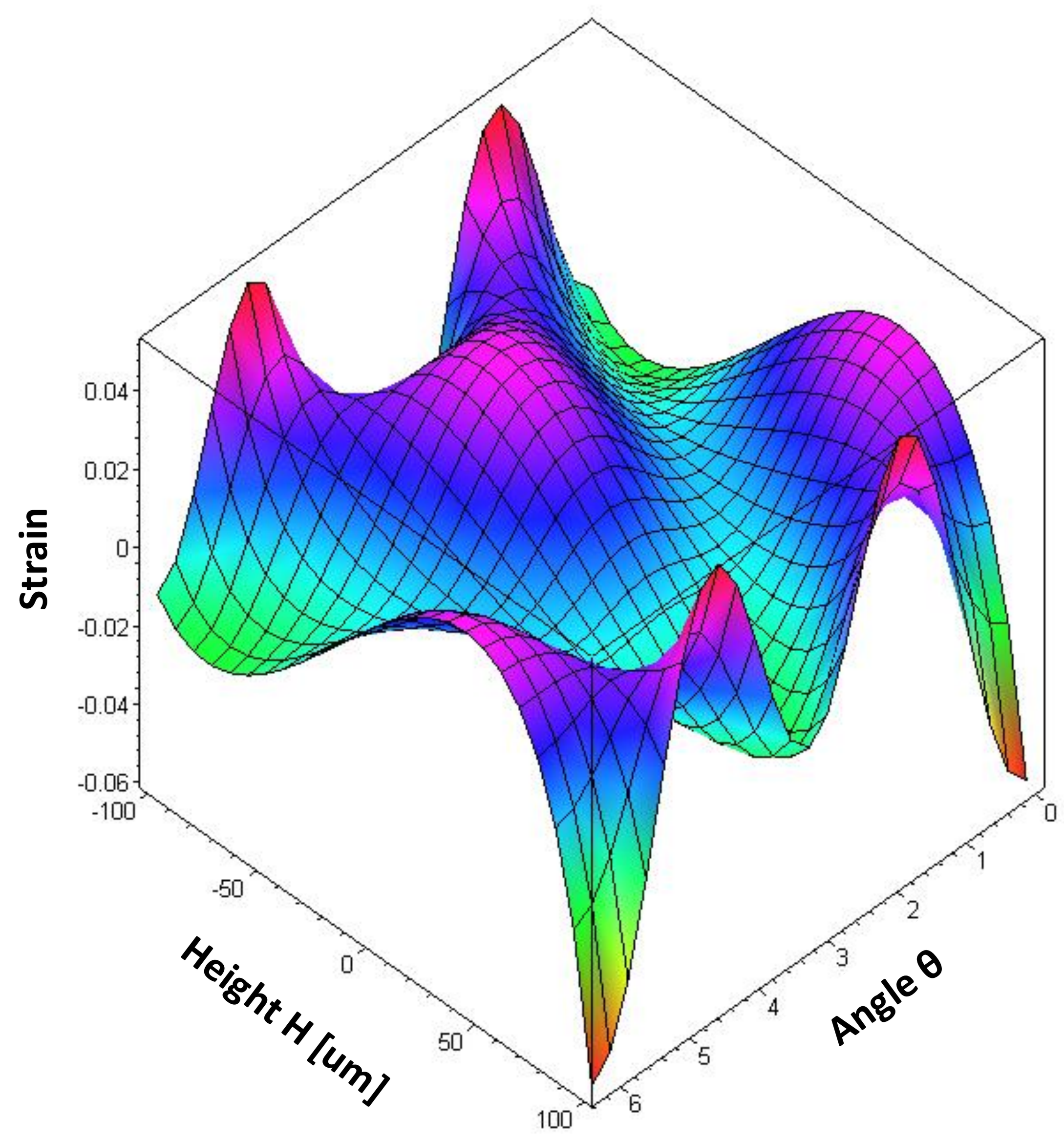
From these equations one obtains for *r(z,θ)*:

$$r(z,\theta) = u(z)\ \cos(\theta) + \left(R(z)^2 - u(z)\sin(\theta)^{\,2}\right)^{1/2}$$

In cylindrical coordinates the surface element dS is defined as:

$$dS = r(z,\theta)\sqrt{1 + \left(\frac{\partial\, r(z,\theta)}{\partial\, z}\right)^2 + \frac{1}{r(z,\theta)^2}\left(\frac{\partial\, r(z,\theta)}{\partial\, \theta}\right)^2}\ dr\ d\theta$$

As a result the strain is plotted below:



It can be seen that maximum tensile strain occurs at the edge of the pad, but not directly in the forward direction. On the contrary at high deflections the forward and backward direction are highly compressive. The extrema in tensile strain are at the origin of joint detoriation.