# Defective Perfection

The allure of perfection must attract many to basic science. An idealized picture of a piece of nature that transcends the actual state in which it is found is very appealing. A perfect crystal with all the atoms on their proper lattice sites, or an atom with all its electrons in their proper orbits—these are things of beauty which submit to elegant theoretical exposition with no loose ends, and all is right with the world. How many useful materials exhibit such perfection? How many would actually be useful if they did? Not many!

And so one is forced to look at defects—those ugly imperfections that destroy symmetries, that make theory less tractable, that offend one's sense of order in the universe, that any self-respecting highfalutin' scientist would eschew. The very words that describe these lowly entities reflect their loathsome state. "Defect" isn't bad enough. There are "dislocations" and, to add insult to injury, there are "misfit" dislocations. There are stacking "faults" and "dumbbell" interstitials. And there are "voids" and the ever ominous "traps." Lest we forget, there is also the catchall "damage" that our perfect materials suffer from the evils of radiation and less exotic encounters with their environment.

As if this weren't bad enough, these imperfections often don't know their proper place or refuse to stay there, corrupting the perfect environment as they go. Vacancies migrate, cracks propagate, impurities diffuse, and dislocations climb and glide. Some rather audacious transgressors even flaunt their presence as color centers. In semiconductors, as if they were the welfare state of matter, the only defects worth their salt must be either donors or acceptors—a most undemocratic stratification. Not willing to be labeled impurities, these pretentious defects call themselves "dopants," implying the higher calling of intentional rather than accidental existence. In their most virulent forms, defects have been known to annihilate.

There are so many types of defects infesting so many types of materials that the potential for material mischief is immense.

A sorry lot these defects be,  
and they make it worse,  
these interlopers, bound or free,  
subject us to the curse  
of fickleness in their effect,  
on the very stuff,  
which we intended to perfect  
to make it good enough  
to use for works as noble as  
an anchor for a ship,  
or for submicron wire paths  
on every IC chip.

It's hard to tell the good guys from the bad. The same dislocations that allow ductility when you want it must be thwarted by inclusions, precipitates, segregants, dispersoids or tangles of their own kind when you don't want it. To scavenge unwanted impurities, we introduce lattice damage to getter them. The same inclusion that nucleates a crack in one circumstance, blunts it in another. Is it any wonder that defects cause stress concentrations not unlike many other facets of modern life!

Not only do defects challenge our capacity to understand and control our materials, they conspire to defy our attempts to concisely and consistently define what they themselves are. Sure, the isolated disruptive influence is easy enough to label. But when they form cooperatives by ordering into superlattices, are they still defects? When lattice damage accumulates to form a continuous amorphous phase, are there defects present at all? If we don't label the perfect surface of the perfect lattice as an imperfection (although some would take issue with this), then is the inner surface of a large void a defect? Is an interface a defect? And if it is, does a misplaced atom make an interface a defective defect? Rather than try to unravel the nested hierarchies of imperfection, it is better to note that these conundrums bring us back full circle to perfection, the only concept that can generically rehabilitate the defect.

If our defects are perfectly disposed in ordered arrays, perfectly concentrated for the optimum strength or conductivity or hue, perfectly controlled so that rejection rates in thousand-step processes are well nigh zero, or perfectly described with elegance formerly only available to pristine counterparts, then our defective perfection is instead perfect defection (to mangle a phrase) and all is again right with a new, richer, highly imperfect materials world.

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