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Staying One Contradiction Ahead Of The Competition

(Case Studies in TRIZ: Computer Chip Cooling)

Introduction

All electronic components, from microprocessors to high end power converters generate heat and rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher throughput in smaller packages, dissipating the heat load becomes a critical design factor. Many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks. This article examines this problem in the context of how TRIZ might enable engineers to develop more capable solutions. The structure is comprised of two main parts. The first of the two parts examines how TRIZ might be used to tackle some of the main contradictions present in the computer chip heat dissipation problem in general. The second part then goes on to examine how the emergence of an effective line of evolution from the first problem in turn leads to a new set of problems. The intended theme of the article is to suggest the importance of actively looking for 'the next' conflicts and contradictions in systems.

1) The Heat Rejection Problem

The computer chip heat dissipation problem is one that has come to dominate the design of new generation devices. Put simply, if we try to improve any given parameter within a design – whether it be speed of operation, or reliability, or whatever – then inevitably something eventually emerges that will prevent any further improvement of the desired parameter. In TRIZ terms, this is a 'limiting contradiction'; something fundamentally stops us from improving the things we would like to improve.

In these situations where fundamental limits have been approached, TRIZ provides the tools to overcome the conflicts and contradictions that have emerged. In order to establish what the conflicting parameters are, it is necessary to ask the important pair of questions 'what would I like to improve?' and 'what is stopping me (or what gets worse)?' Asking those questions for a typical chip we might obtain:-

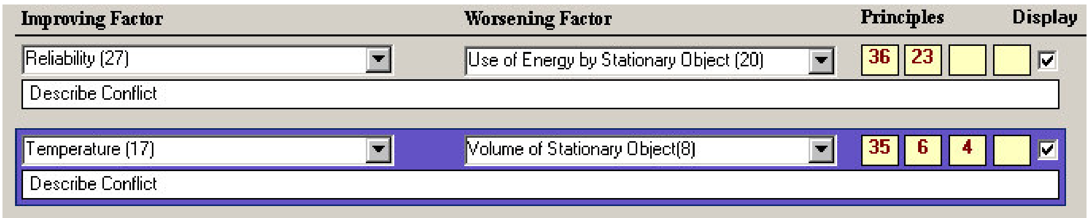
What would I like to improve?
Lower heat generation
Better heat dissipation
Reliability

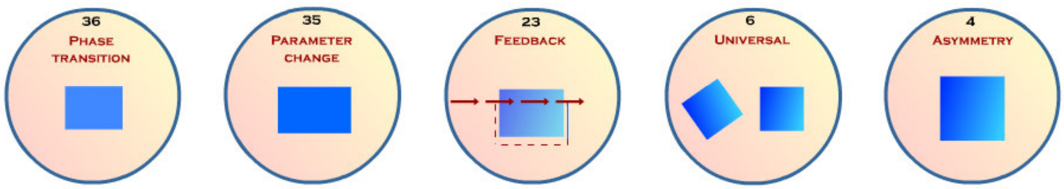
What is it that gets worse?
What is it that stops me?
Size of chips is getting smaller
Heat conduction properties of the materials used in the construction

Having then identified pairs of things in conflict with one another, it is then necessary to convert them into things that match parameters contained in the Contradiction Matrix in order to tap into the means by which others might have solved similar problems. In this case we would get something like:-

Lower heat generation	Temperature
Better heat dissipation	Temperature
Reliability	Reliability
Size of chips is getting smaller	Volume (Stationary)
Heat conduction capability of metal	Use of Energy

Which in terms of the Matrix then gives…





Most common 2nd 3rd 4th 5th

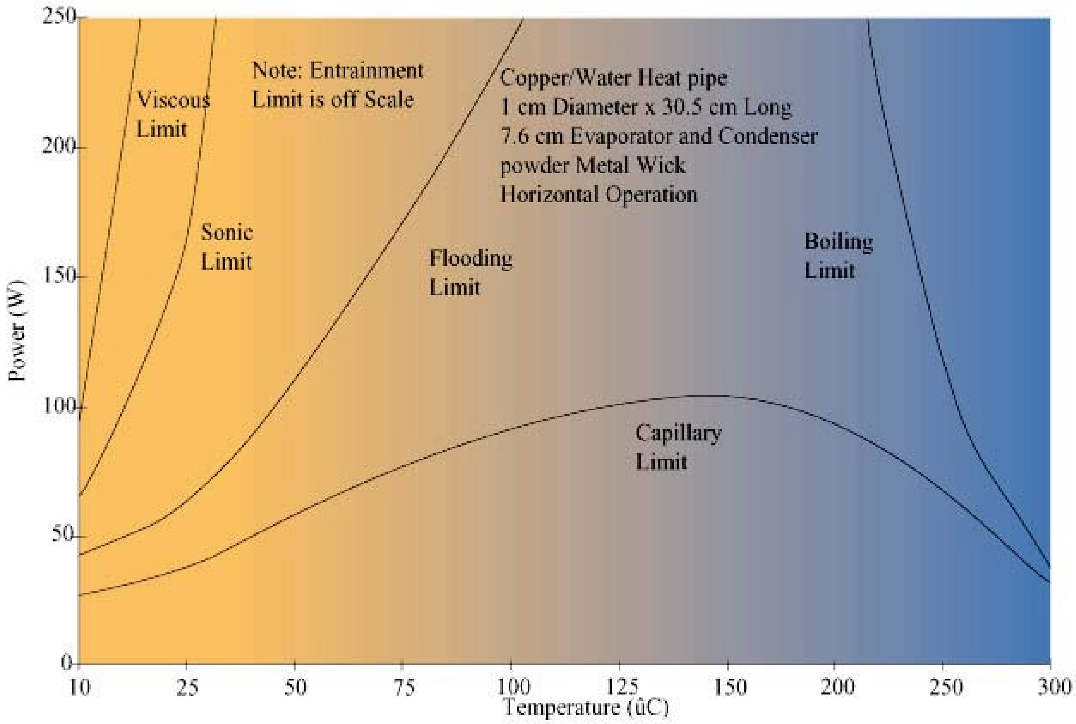
From here it shouldn't take too long – particularly if we observe some of the previous uses of Principle 36 contained in the list of Inventive Principles with Examples from Hands-On systematic Innovation – to derive the idea of using a heat pipe to help solve the defined conflicts.

Heat pipes, of course, are becoming increasingly common in computer systems and particularly so in laptop machines – where the available space is even more limited than in desktop and other machines. In this sense, the case study so far is really only about how TRIZ might have helped to generate such a solution in the first place. The bigger issue at stake in this article is about the general situation now, and what happens as the new contradictions begin to emerge during the push to advance heat-pipe technology to the limits of its capability. This state now acts as the start point for the second part of the case – staying one contradiction ahead of the competition:

2) Heat-Pipe Contradictions

Although there is nothing to say that heat-pipes will continue to have a role in the evolution of more effective electronic devices (after all, they are only present to dissipate heat that we would much rather was never generated in the first place – but that's another story), it does appear that they offer a sufficient level of ideality to warrant at least their consideration for some time to come. This being the case, anyone seriously involved in the business of deploying heat-pipes in electronic applications would be well advised to identify the conflicts and contradictions that might be expected to limit future advance of the technology.

Towards this end, it appears clear that certain sectors of the industry have already done a good job of constructing this picture, albeit they have done it without recognizing the links to TRIZ and the crucial role of conflict elimination in the evolution process. The figure below reproduces a graph from Reference 1. The graph illustrates two of the main parameters affecting the performance of a heat-pipe – temperature and power. It has also



identified (assumedly via experiment) the performance boundaries that determine the environments within which the heat-pipe either will or will not function.

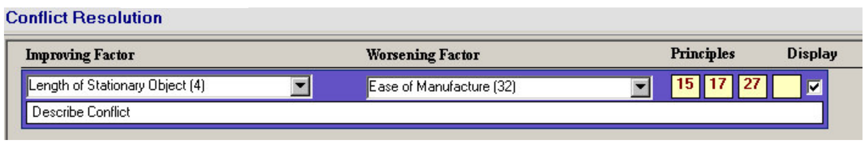
The normal practice once maps like this have been constructed is to assume that the limits are fundamental – that, to take but one example, the capillary limit of the heat-pipe will fundamentally prevent operation below a certain power level. This type of thinking is, TRIZ teaches us, the stuff of trade-off and compromise. The TRIZ perspective is that these limits are relevant only for the current system. Shifting to another system would shift the line (or possibly eliminate it altogether).

This idea of 'shifting to another system' doesn't mean that we completely throw away the current heat-pipe and start again. Rather, it simply means that some element of the system might be required to change.

Reference 1 does an excellent job of identifying what the key trade-offs associated with the heat-pipe are – see the Table below:

Heat Transport Limit	Description	Cause	Potential Solution
Viscous	Viscous forces prevent vapor flow in the heat pipe	Heat pipe operating below recommended operating temperature	Increase heat pipe operating temperature or find alternative working fluid
Sonic	Vapor flow reaches sonic velocity when exiting heat pipe evaporator resulting in a constant heat pipe transport power and large temperature gradients	Power/temperature combination, too much power at low operating temperature	This is typically only a problem at start-up. The heat pipe will carry a set power and the large ^T will self correct as the heat pipe warms up
Entrainment/ Flooding	High velocity vapor flow prevents condensate from returning to evaporator	Heat pipe operating above designed power input or at too low an operating temperature	Increase vapor space diameter or operating temperature
Capillary	Sum of gravitational, liquid and vapor flow pressure drops exceed the capillary pumping head of the heat pipe wick structure	Heat pipe input power exceeds the design heat transport capacity of the heat pipe	Modify heat pipe wick structure design or reduce power input
Boiling	Film boiling in heat pipe evaporator typically initiates at 5-10 W/cm^2 for screen wicks and 20-30 W/cm^2 for powder metal wicks	High radial heat flux causes film boiling resulting in heat pipe dryout and large thermal resistances	Use a wick with a higher heat flux capacity or spread out the heat load

Unfortunately, all of the suggested 'potential solutions' are ones either based on trade-off and compromise ('move the capillary limit by reducing the power input' for example) or ones that offer little clue as to **how** they might be physically realized ('modify heat-pipe wick structure design'). This is where TRIZ can again help. So, to take one example a stage further we might look at the 'modify wick structure' suggestion and try and identify the conflicts and contradictions present. For a typical current generation design, we might see the presence of a conflict between the desire to reduce the size of the fins in the pipe in order to improve heat transfer capability, fighting a likely increase in the difficulty of manufacturing the system. For this particular conflict, we might then obtain:-



Resolution of this length versus manufacturability conflict – possibly using one or more of the Inventive Principles that other sectors have already successfully used to challenge the conflict – would then enable a shift in the state of the art and as a result the drawing of a different – more ideal limit line on the performance map.

Whether the heat-pipe wick structure question is the 'right' next one in the evolution of heat-pipes for electronic applications or not is irrelevant to the context of this article. Our context here is merely to highlight the importance of establishing what the 'new' contradictions are whenever we develop a new solution.

This does not mean that we have to either solve the new contradiction or implement the solution we come up with, simply that we should know the evolution route map well enough to know where the next limitations are going to emerge. Of course, if we are serious players in a given arena like heat-pipe technology, then it is very definitely in our interest to have generated solutions to the 'next contradiction'. Even though we might chose not to put those solutions on the market yet, for most it is important from strategic and intellectual property perspectives to stay one contradiction ahead of our competitors.

Summary

Evolution towards ideal final result end-points occurs through the successive emergence and resolution of conflicts and contradictions in any kind of system (Reference 2). It is always a good idea to know a) what the 'next' limiting contradiction in any system is going to be, and b) how the conflict can be resolved. Market demand will tell us when it is the right time to launch a new (potentially disruptive) solution. In the meantime, it is very definitely a good idea to protect the contradiction-breaking solutions we develop.

References

1) Garner, S.D., 'Heat pipes for electronics cooling applications', http://www.electronics-cooling.com/Resources/EC_Articles/SEP96/sep96_02.htm
2) Mann, D.L., 'Contradiction Chains', TRIZ Journal, January 2001.

More Root Cause Analysis Paralysis (How Much Data Is Enough?)

We seem to have been making ourselves very unpopular in recent months with experts and devotees of root-cause analysis methods of problem solving. A large part of that unpopularity seems to have emerged from either the article we published in TRIZ Journal last year (Reference 1), or whenever we show slides with the words ‘root cause analysis paralysis’ printed on them. Our aim in both instances is to be provocative of course. But provocative with strong justification, we believe, since we seem to spend far too much of our time being asked to solve problems where the thirst for data in trying to locate root causes has caused all perspective on the economics of the situation to be lost. This article tries to clarify our position for any of those people we have inadvertently offended in the recent past.

Let us begin by thinking about problems. Two basic scenarios should suffice to cover the relevant spectrum of possibilities. In the first we have a situation in which a problem has always been there, but we only just had to start worrying about it (nobody cared about defect rates at the start of the computer chip industry for example because everyone was making so much money from the good chips). In this case there is a clear need to acquire some data to find out what is happening. We need to ask ‘why?’ Why does the problem exist? We might conduct some experiments on the system to try and establish the conditions that make the problem disappear. This is the data we need in order that we might make some kind of reasoned decision on how to solve the problem. There is little getting around this need other than to make un-reasoned decisions. Which does happen, but not generally in organizations that stick around for very long. So, if we have **no** data, then we need to get some.

In the second scenario, a problem emerges because something has changed. In this situation we already have some data – we know that we have crossed some kind of a boundary; on one side of which there is no problem and on the other there is. In this kind of scenario there is usually a very strong desire to collect or acquire a bunch of data to explore the problem/no-problem boundary more completely – to understand how all of the possible system variables affect the whether the problem occurs or not.

The two scenarios define opposite sides of the root-cause-analysis versus root-cause-analysis-paralysis coin. Sensible problem solving requires the presence of data. The new problem then becomes one of balancing the cost of acquiring the data versus the benefit that solving the problem might bring. No data is bad. Too much data is equally bad. Root cause analysis recognizes the first statement, but rarely the second.

Root cause analysis likes data. Lots of it. The more the better. There is no concept of ‘enough’ in root cause analysis.

This often unquenchable thirst for more data is the result of some very deeply engrained psychological inertia effects. Usually two that are significant: 1) The more data I have acquired, the more it looks and feels like I understand the system. Psychological inertia here is particularly cruel. It tells us that if we have acquired all this data and still don’t get to solve the problem, it *must* be because we haven’t acquired enough yet. Data breeds data breeds data. Often way beyond the bounds of common sense.

2) The more data I have acquired, the more I will have to discard if (when) the system changes. Discarding large quantities of expensive data is not something that comes easily to us. Consequently, the data encourages us to stick with the current system, and the more data we have, the more we 'lose' if we shift to a new system. Sticking with the current system and not being able to solve the problem sends us around a new vicious circle that says we just haven't found the 'right' data yet, and should therefore keep looking until we find it.

Simple economics should tell us that there is definitely such a thing as 'too much data'.

So in the first scenario we could see there was too little data, and in the second there is a tendency to get too much. Too much data? Too little data? Hmm. Perhaps this could be a contradiction?

Should we try and work out, therefore, what the 'right' amount of data is? Do the trade-off calculations? Or should we try and eliminate the contradiction?

TRIZ would encourage us to think about the second option. In fact, it would further suggest that in this kind of too-little versus too-much trade-off situation, it is actually not the data we should be focusing on at all. Or at least not the type of data root cause analysis asks us to acquire. Use of Inventive Principle 35 – Parameter Changes – to challenge the contradiction may suggest the need for some *different type* of data.

Root cause analysis is a tool of trade-off and optimization. It requires us to acquire data that will enable us to make the trade-off and optimization decisions as effectively as possible. It will enable us to plot the boundaries between problem and no-problem. What if this is the 'wrong sort of data'?

So What Is The Alternative?

Very simply, consider the possibility that the 'root cause' of any problem you are facing is that your system has hit a fundamental limit.

Difficult as it might be to believe, it is our experience that 80-90% of all the problem solving cases we come up against are precisely in this situation. If we take a moment to think about why this might be so, we might start to think about how the role of engineers and designers is to get as much as possible out of a system, to push designs as hard as possible, and that therefore, they are inherently driving systems towards the limits of their capability, to the top of their s-curve right from day one.

When a system has reached this state, there is simply no point in investing money to acquire more trade-off and optimization data. Fundamental, in system evolution terms, unfortunately means fundamental. You would like to improve some aspect of a system and something is stopping you from doing it. Hey, you have found a contradiction. It applies to both of the problem scenarios at the beginning of the article. In the first scenario, the thing you want to improve is the problem; and you need to identify the 'what's stopping' part. In the second scenario, you already know what has changed in your system, and so already have a good idea of what is in conflict with what else. In both situations, we say save your root-cause analysis data acquisition time and money and invest it instead in resolving the contradictions. Resolving contradictions breaks us out of the trade-off and optimization mindset. It enables us to find new s-curves.

This limit-finding activity is something we call ‘root contradiction analysis’ (Reference 2). In the first instance it involves asking a pair of questions. 1) What is it that we would like to improve? 2) What is it that is stopping us (or gets worse)? While answering these questions – or the second one at least – may not be immediately obvious (in which case, that’s where we need to focus our data finding activities), overwhelming evidence suggests that it is a much more effective use of time than setting up a programme of experiments to ‘acquire more data’ to feed root cause analysis methods.

Its not about data, it’s about the right kind of data.

Root cause analysis encourages us to find trade-off and optimisation data. Numbers. Root contradiction analysis encourages us to find out what is stopping the system from improving. Parameters. Parameters tend to be easier to identify than numbers. They are also very much cheaper. Even more important, the benefits of solving the root contradiction are very often many times greater than a trade-off and optimization solution.

Less money and a better solution? Now that sounds like our kind of contradiction.

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1) Mann, D.L., ‘Root Cause Analysis Paralysis’, TRIZ Journal, May 2002.
2) Mann, D.L., ‘Hands-On Systematic Innovation’, CREAX Press, 2002.

Humour – The Mullet

Those of us blessed with a full head of hair often face difficult decisions when it comes time to tell the barber how much to take off; should we cut it short or leave it long? Both have their merits and problems. Some of us take a trade-off approach to the decision. But others have realized that because the ‘long or short’ question is a physical contradiction, it is amenable to more inventive solution. The mullet – Figure 1 – is one such example. An example that uses separation in space as the inventive strategy;

Where do I want my hair *short*? Around my eyes, and on top of my head.
Where do I want my hair *long*? At the back.

Figure 1 – A Typical Mullet Haircut
(from Reference 1)

As discussed in Reference 2, the ‘separate in space’ solution to the hair length contradiction has been with us since the Iron Age, thus making it one of the very earliest uses of TRIZ. Well, sort of.

Health Warning: Mullet haircuts can seriously damage your credibility.

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1) **www.mulletsgalore.com**
2) Larson, M., Hoskyns, B., ‘The Mullet: Hairstyle of the Gods’, Bloomsbury, London, 1999.

Patent of the Month

Since the theme of this month's newsletter is micro-electronics, we have a double patent-of-the-month this month; the first being the best patent granted during April in the vicinity of the world of electronics, and the second being our favourite out of all of the patents we reviewed during the month.

The first patent, then, is US6,548,956 awarded to inventors at Princeton in the US on April 15. The patent describes 'transparent contacts for organic devices', and is essentially related to efficient, low-cost, high definition means of generating colour displays in a variety of electronic systems oriented applications. From the abstract of the invention disclosure we find:-

A multicolor organic light emitting device employs vertically stacked layers of double heterostructure devices which are fabricated from organic compounds. The vertical stacked structure is formed on a glass base having a transparent coating of ITO or similar metal to provide a substrate. Deposited on the substrate is the vertical stacked arrangement of three double heterostructure devices, each fabricated from a suitable organic material. Stacking is implemented such that the double heterostructure with the longest wavelength is on the top of the stack. This constitutes the device emitting red light on the top with the device having the shortest wavelength, namely, the device emitting blue light, on the bottom of the stack. Located between the red and blue device structures is the green device structure. The devices are configured as stacked to provide a staircase profile whereby each device is separated from the other by a thin transparent conductive contact layer to enable light emanating from each of the devices to pass through the semitransparent contacts and through the lower device structures while further enabling each of the devices to receive a selective bias. The devices are substantially transparent when de-energized, making them useful for heads-up display applications.

The key inventive step here appears to be the harnessing of organic structures to achieve the necessary colour resolution. As such, it represents an application of Inventive Principle 35 – one making a quite substantial shift in the means of delivering the intended function relative to the previous state of the art. The shift from traditional mechanical to biological parameters seems, in fact, to be a growing trend.

Our main patent of the month may also turn out to have considerable application in micro-electronic applications. As it is, the capability made possible by US6,548,264 'coated nano-particles' granted to the University of Florida also on 15 April, opens up a whole cluster of potential opportunities in the longer term. Regular readers of our newsletter will be aware of our interest in the nano-technology arena thanks to the significance suggested by the TRIZ 'macro-to-nano' trend.

As suggested in the Background to the Invention, the ability to form nano-particles consisting of more than one type of material (i.e. being able to add a coating material of one type to a core consisting of another) enables a much broader range of functions to be delivered in the same sized particle. A summary from the invention disclosure:-

Nanoparticles are very small particles typically ranging in size from as small as one nanometer to as large as several hundred nanometers in diameter. Their small size allows nanoparticles to be exploited to produce a variety of products such as dyes and pigments; aesthetic or functional coatings; tools for biological discovery, medical imaging, and therapeutics; magnetic recording media; quantum dots; and even uniform and nanosize semiconductors.

Nanoparticles can be simple aggregations of molecules or they can be structured into two or more layers of different substances. For example, simple nanoparticles consisting of magnetite or maghemite can be used in magnetic applications (e.g., MRI contrast agents, cell separation tools, or data storage). More complex nanoparticles can consist of a core made of one substance and a shell made of another.

Many different type of small particles (nanoparticles or micron-sized particles) are commercially available from several different manufacturers including: Bangs Laboratories (Fishers, Ind.); Promega (Madison, Wis.); Dynal Inc.(Lake Success, N.Y.); Advanced Magnetics Inc.(Surrey, U.K.); CPG Inc.(Lincoln Park, N.J.); Cortex Biochem (San Leandro, Calif.); European Institute of Science (Lund, Sweden); Ferrofluidics Corp. (Nashua, N.H.); FeRx Inc.; (San Diego, Calif.); Immunicon Corp.; (Huntingdon Valley, Pa.); Magnetically Delivered Therapeutics Inc. (San Diego, Calif.); Miltenyi Biotec GmbH (USA); Microcaps GmbH (Rostock, Germany); PolyMicrospheres Inc. (Indianapolis, Ind.); Scigen Ltd.(Kent, U.K.); Seradyn Inc.; (Indianapolis, Ind.); and Spherotech Inc. (Libertyville, Ill.). Most of these particles are made using conventional techniques, such as grinding and milling, emulsion polymerization, block copolymerization, and microemulsion.

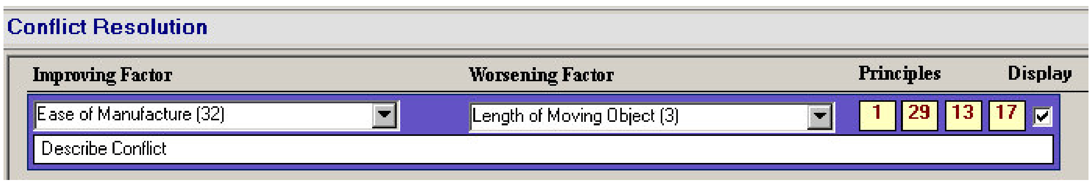
Methods of making silica nanoparticles have also been reported. The processes involve crystallite core aggregation, fortification of superparamagnetic polymer nanoparticles with intercalated silica and microwave-mediated self-assembly. Unfortunately, these techniques have not proven to be particularly efficient for consistently fabricating nanoparticles with a particular size, shape and size distribution.

In simplest terms, the invention represents a jump along the Mono-Bi-Poly (Various) trends. The application of a coating of some description to a structure is a very common application of the trend. It is one that is always worth bearing in mind for any kind of physical object – no matter how small it might be.

This particular invention relates to a new method for preparing nanoparticles having a core enveloped by a silica shell. The silica layer offers a number of new function opportunities – including increasing transparency, bio-compatibility, stability over long periods of time (useful in preserving pigments, for example, in dyes) and chemical inertness. The invention disclosure suggests a number of potential applications that might take advantage of these opportunities:-

“Many applications are specifically envisioned including, for example, cell labeling, targeted drug or gene delivery, biosensors, magnetic recording media, magnetic resonance imaging, and use in micro- or nano-sized machines. For example, cytotoxic drugs or viral vectors carrying therapeutic genes can be attached to the functional groups on the surface of nanoparticles. These nanoparticles can then be dispersed in a pharmaceutically acceptable carrier (e.g., USP grade saline) and administered to a patient (e.g., by intravenous injection). Magnetic fields can then be used to concentrate the virus or drug at the delivery site to enhance site-specific uptake (e.g., by placing a magnet at the site). Drugs coated onto nanoparticles can be further contained within a time-release coating (e.g., a biodegradable sugar) so that the drug can accumulate at the site before becoming active. In other envisioned examples, fluorescence-based biosensors can be attached to the particles. The resulting particles can be manipulated by magnetic means into specific target sites (specific locations in isolated cells), and used to monitor biochemical processes in situ. The nanoparticles of the invention are also thought to be useful for enhancing Magnetic Resonance Images (MRI). For example, as described above, antibody or ligand-coated nanospheres can be caused to accumulate at sites in the body where the target antigen or receptor is concentrated or located. In comparison to non-targeted MRI contrast agents, the increased concentration of particles at a targeted site will enhance the contrast in an MRI. Nanoparticles manufactured in a stable, single domain size range that allows a remnant magnetization to be preserved are envisioned to be useful in binary magnetic recording applications where they can be substituted for the simple iron particles used in conventional magnetic storage devices. One particular example would be micromechanical gate activation upon application of an external magnetic field.

The invention disclosure details previous state of the art difficulties when trying to apply a coating to a nano-particle, showing that typically there is a conflict present between the desire for a homogenously sized end-product (i.e. one with an even depth of coating) and the difficulties of actually being able to manufacture it. From the contradiction perspective, the conflict tackled by the inventors may be seen as:-



The strategies used by the inventors to overcome the contradiction are outlined in the following excerpt from the invention disclosure:-

The invention is based on a method for preparing silica-coated nanoparticles using a water-in-oil microemulsion. The method yields uniformly-sized particles composed of a core enveloped by a silica shell. The microemulsion is made by combining a relatively polar liquid such as water, a relatively non-polar liquid such as a liquid alkane, and one or more surfactants to form an isotropic, thermodynamically stable single-phase system. This system is comprised of a plurality of very small spherical water pools (i.e., reverse micelles) that serve as reactors for producing nanoparticle cores.

The inventors, in other words, managed to use the two most frequently applied Inventive Principles (1- Segmentation, and 29 – Fluids) to solve this type of conflict situation based on the original TRIZ research.

Irrespective of the consistency with the recommendations of TRIZ, we like the patent most due to the new capabilities it offers up across such a very wide range of applications. As such, we would place it in the Level 4 category, and anticipate the future creation of a host of lower Level patents making use of the idea created by the inventors.

Best of the Month

Sorry, a big fat combined zero from any of the recognized TRIZ sources to recommend you spend your reading time on this month.

If you're desparate for something to read, try Clockspeed from Charles Fine. The book came out in 1998, but provides an excellent series of business case studies to provide an interesting model of why business systems tend to oscillate between modularization and integration. The TRIZ increasing-decreasing complexity trend in so many words.

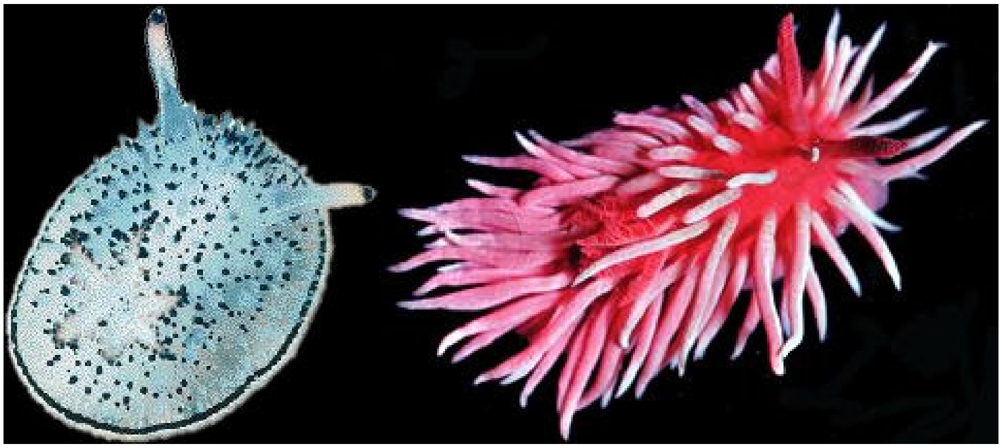
Investments – Flat Motors

This month we came across an article in Eureka magazine in the UK concerning two of our favourite things; electric motors and Russian engineering talent. The Ultra Motor Company (www.solus-strategic.com) has posted the following information about what appears to be a step-change beyond state of the art in non-rare-earth (i.e. it will be low cost) motors on their website:-

In conventional electro-mechanical terms our Ultra Slim motor could be described as an inside-out, planar coil, harmonic offset, permanent magnet DC motor. Due to our novel configuration of stator and rotor poles our Ultra Slim motors combine higher electrical efficiency, much greater torque and reduced electro-magnetic 'noise'.
As its name suggests, the Ultra Slim is much thinner (has a higher aspect ratio) than any other pancake style motor but capable of delivering 2 to 4 times the torque of other low speed DC motors suitable for direct drive applications. The motor is voltage pulsed, which allows effective electrical regeneration between 'drive' pulses. The Ultra Slim can be controlled by a conventional commutator or electronically.
For transportation applications where the Ultra Slim is ideally suited to relatively large diameter, slim wheel motor applications typified in pedelecs, e-bikes, e-rickshaws and retro-fit e-wheelchairs, our higher electrical efficiency allows range to be doubled using identical battery packs. For in-situation applications such as direct drive white goods and industrial applications, significant space savings and electricity consumption savings can be obtained.

We'll be investigating further and will keep you informed if anything interesting turns up.

TRIZ and Biology – Sea Slugs



Nudibranchs, or sea slugs, feed on the sea anemone. This is a problem for other forms of sea-life since anemones have poison harpoons that stick out and would paralyze anything that came in contact with it. The sea slug, however, is able to ingest these harpoons and store them (either inside its own stomach or to pass them through the stomach wall and into protruding spines of their own) in order to prevent other predators from eating them. This capability represents an excellent use of Inventive Principles 22, Blessing in Disguise – ‘transform harmful effects so that they deliver a positive effect’.

Some nudibranchs are also able take in and store some of the coloring substances from the food they eat. If a certain nudibranch eats a red sponge, it can store some of the sponge's red pigment in its body, and turn red too – thus creating an ability to camouflage itself and make it more difficult for potential predators to locate. Some nudibranchs have also established that they only have to pretend to be poisonous – so long as some of the species are, then predators are very unlikely to take a gamble on whether any individual slug is poisonous or not (Principle 2, ‘Taking Out’).