Heat is the Enemy of Energy Efficiency: a Novel Material for Thermal Management

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ABSTRACT

Control over the flow of heat has been a major challenge to engineers for centuries. A modern day example is a data center, where cooling accounts for 50% of the total energy costs. At the structural scale, a dark colored roof will increase the air conditioning load. Inside the building, the metal enclosures of the servers will trap and re-radiate heat internally. At a semiconductor scale, the processing power of the chips themselves is limited by their ability to dissipate heat.

A new nano-chemical, developed by TAG Technologies, can impede the flow of heat through materials in one direction only. This new material can be added to almost any product to control the flow of heat, save energy, and reduce greenhouse gas emissions.

Examples are presented in this paper including data centers, cool roofs, consumer goods packaging, refrigerated shipping, automotive, high voltage electrical conductors, and semi-conductors.

Keywords: thermal management, energy efficiency, data center, cool roof, semiconductor, greenhouse gas

1 INTRODUCTION

Engineers facing thermal issues should now consider the use of TAG technology, a novel material technology which can impede the flow of heat in one direction only.

This new material can be added to almost any product to control the flow of heat, save energy, and reduce greenhouse gas emissions. This paper describes:

- How TAG technology increases the infrared rejection and emissivity of a surface, thereby impeding the flow of heat in one direction while increasing its flow in the other.
- The example of a data center which shows the many applications where TAG could be used to increase the overall efficiency of the operation.
- How a TAG coated “cool roof” would pay back in 3 years compared to 4 years for the best competing technology.
- How TAG technology can improve thermal management in a range of other applications including consumer goods packaging, electronics, logistics, industrial processes, electrical transmission, automotive, and semiconductors.
- How, when assessing the applicability of TAG technology and tuning its characteristics, a number of factors must be considered.
- The future focus of research into TAG technology.

2 DESCRIPTION OF TAG TECHNOLOGY

TAG® is a unique additive to paints, coatings, membranes and films that can slash the cost of heating or cooling anything.

When added to a polymer matrix, TAG creates an interference effect, similar to a diffraction grating, blocking inbound radiant energy at the desired wavelengths while increasing the outbound emissivity in desired wavelengths.

Through this mechanism, TAG increases the effective infrared rejection and emissivity of a surface, thereby impeding the flow of heat in one direction while increasing its flow in the other (Figure 1).

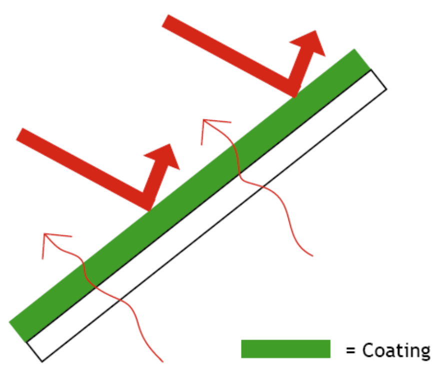

Figure 1: TAG Mechanism

The electromagnetic mechanism of TAG is still under investigation. Based on work carried out at Australia’s leading energy technology research organization, the University of New South Wales, the increase in infrared rejection compared to a bright white surface is approximately 15% [1]. Our testing has also shown the emissivity compared to a black surface to be increased by around 7% for the selected wavelengths.

More importantly for commercialization, empirical testing by third parties has shown a significant beneficial impact in a number of industrial applications, several examples of which will be described in this document.

The mechanism of TAG is not influenced by color. Therefore, designers can get thermal performance as well as aesthetic appeal. Figure 2 shows the impact of TAG on the heating and cooling curve of a black painted sample under a standard sun. The untreated sample is the topmost curve. The underside of the TAG treated sample was significantly cooler as shown in the curve below. A bright white sample is shown on the bottom curve for reference. TAG has even been shown to have a similar beneficial effect in clear films for windows.

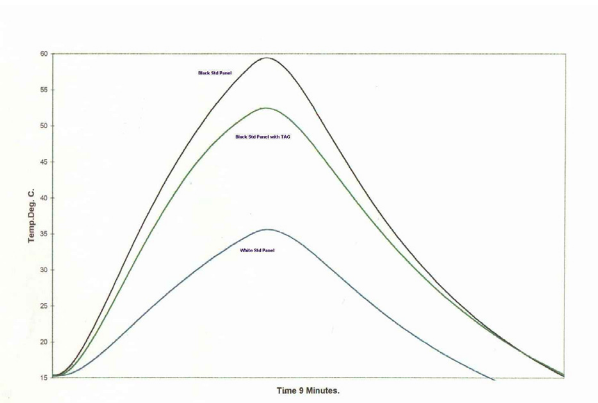

Figure 2: Impact of TAG on a Black Sample

A key benefit of the one-way effect of TAG, when compared to the use of insulation in thermal control, is that insulation slows the flow of heat in both directions. For example, the insulation of a building may slow the rate of heating during the day, but once the sun goes down it also slows the rate at which the interior can cool.

The TAG material is an organic compound which is non-toxic and indeed edible. The exact nature of the compound will be revealed in future papers subject to progress in IP protection. Considerable intellectual property and know-how is associated with the tuning of TAG to specific parts of the electromagnetic spectrum.

3 DATA CENTER EXAMPLE

According to the Lawrence Berkeley Lab, about 17 percent of US server farms are located in the San Francisco Bay Area and Silicon Valley, requiring about 80 megawatts of power to run. Aggregate electricity use for servers doubled over the period 2000 to 2005 both in the U.S. and worldwide. Of that increase in power usage, 90% is due to an increase in the volume of servers in data centers [2]. Blade servers are an important part of this growth and tend to increase the power usage and density, while methods such as server virtualization decrease usage but increase power density. These trends will exacerbate both equipment and data center cooling issues for designers.

In the data center of the future, TAG could be used on the roof, cladding, ducting, plant, racks, enclosures of routers and servers, heat sinks, even the chips themselves to improve the dissipation of heat. In an integrated design, TAG could be used to optimize the flow of heat from the processor and electrical equipment and out into the environment.

Cooling accounts for 50% of energy costs in a typical data center [3], while thermal issues also have a significant impact on the energy efficiency of the servers, routers and power conversion equipment.

The building envelope is a simple entry point for the use of TAG in data centers. Paint enhanced with TAG could be applied to the roof to reduce the solar load on the air-conditioning. In California, such a project would be partially subsidized by the local utility as a demand management measure.

We have recently modeled the impact of a TAG coating compared to a dark colored roof and the best available current "cool roof" technology. The model was based on the DOE Cool Roof Calculator developed by the Oak Ridge National Laboratory (www.ornl.gov), the product data base at the Cool Roof Rating Council (www.coolroofs.org), the paint manufacturers' data sheets, and discussions with roofing companies.

We assumed a 100,000 square foot building located in Sacramento, California with an existing R-5 roof and an "average" existing cooling and heating system (i.e. this example does not have the high internal heat loads of a dedicated data center).

As shown in Table 1 below, TAG reduces the cooling load by increasing the effective solar reflectance and infrared emmittance of the roof. Moreover, unlike other cool roof technologies, TAG does not have a deleterious impact on heating costs during winter. This is because the TAG can be tuned so that infrared emmittance at those wave lengths are reduced. This peculiar effect is also extremely valuable when significant amounts of heat are being produced inside the building, e.g. in a data center.

A TAG coated roof would pay back in 3 years compared to 4 years for the best competing technology, while the first cost is only 12% higher. Importantly, the investment payback is now much less than the critical 4 year (~25%) hurdle rate.

Longevity is a concern for building owners. A typical "best in class" cool roof coating has a solar reflectance of 88% when new, but this will fall to 84% after 3 years due to weathering. Moreover accumulated dirt can reduce solar reflectance down to as little as 60-65%. The unique mechanism of TAG means that the effect of weathering is significantly reduced while dust has no impact on TAG.

Item	**Black Roof**	**Light Roof**	**Best Current Cool Roof**	**Cool Roof with TAG**
Cooling Load [Btu/ft²/ year]	15,398	9,377	2,980	1,372
Heating Load [Btu/ft²/year]	16,955	16,210	20,560	16,210
Cooling Saved ($)		8,800	18,200	20,562
Heating Saved ($)		1,500	(7,000)	n/a
Demand Charge Saved		6,600	13,300	14,906
Total Energy Cost Saving		16,900	24,500	35,468
Savings c.f. Light Roof			45%	110%
Total Cost of Painting ($)		99,000	101,280	111,792
Total Cost/sf		$0.99	$1.01	$1.12
Pay Back (years)		5.9	4.1	3.2

Table 1: Comparison of Cool Roof Technologies

While savings are important to building owners, internal temperatures are interesting from both the point of view of actual temperatures, and the perception of occupants. Independent testing [4] showed that TAG could keep the interior of a building 3ºC to 7ºC (5.4~12.6ºF) cooler. As a rule of thumb, up to 50% more energy is required to decrease temperature by each additional 1 degree Celsius.

Much of this reduction is radiant heat from the interior surfaces of the building. A further rule of thumb is that where mean radiant temperature (MRT) differs from air temperature by more than 2ºC, every 1ºC rise in MRT requires a compensating drop in DBT of approximately 2ºC [4]. This would therefore imply that the use of TAG to reduce the MRT might allow an increase in the air temperature, i.e. under cooling conditions the thermostat could be set higher to achieve the same level of perceived comfort at an even lower cost.

4 OTHER APPLICATIONS

This new material can be added to almost any product to control the flow of heat, save energy, and reduce greenhouse gas emissions.

For consumer packaged goods, independent testing of aluminum beverage cans coated with TAG showed 50% faster cooling. This type of application can lead to coatings that keep beverage cans colder longer, or cook food in cans much faster, to speed production filling lines or enable faster turnover at retail locations. Similar tests with food packaging demonstrated that food could last 60% longer in retail stores, resulting in substantial reductions in waste.

Another important part of the supply chain where TAG finds application is in shipping containers. Independent testing by the Kuwait Institute of Scientific Research found that the interior of containers painted with a TAG coating closely tracked the ambient temperature in the shade, and remained 9 to 14°C cooler than an un-insulated container and a surprising 7-11°C cooler than an insulated container. These differences would represent significant savings on logistic costs and wastage.

In automotive applications, TAG could help boost driver comfort and fuel efficiency. Independent testing of armored vehicles showed that TAG paint could keep the interiors 23% cooler at the peak of the day. TAG can also be used on engine components to increase the efficiency of heat dissipation, cool the engine, and increase the overall fuel efficiency.

Another application for TAG is reducing the temperature of high voltage conductors (Figure 3). Independent testing by Downer Industries showed that a clear coating containing TAG was able to reduce conductor temperature by 23°C, resulting in a sag reduction of 235% compared to the control. Using TAG would allow a T&D company to reduce power line sag for a given current (thereby increasing life or reducing maintenance) or increase the current capacity for given sag (thereby increasing the carrying capacity of the transmission line).

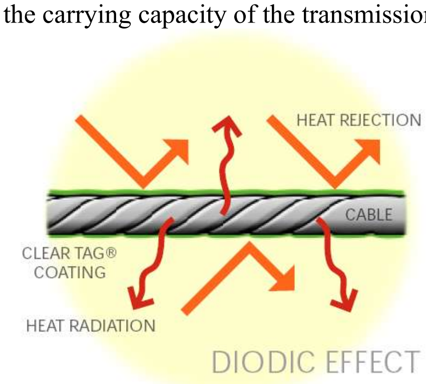

Figure 3: Impact on High Voltage Conductor

Thermal management is a particular concern for the semiconductor industry. The trend for higher power in smaller chips means that the heat flux of today's chips is similar to that experienced by the tiles of the space shuttle upon re-entry into the Earth's atmosphere. Unless this heat flux is addressed, chip performance can be reduced or the chip's lifespan could by shortened. Further research is required to determine the application of TAG in semiconductor packaging.

5 ASSESSING TAG APPLICATIONS

Assessing the applicability of TAG technology requires an understanding of the specific thermal issues to be solved, the chemical composition of the host polymer, the impact of substrates, and the design of measurement techniques used to tune the additive to a particular application. These issues will be the subject of future papers.

6 FUTURE RESEARCH

Future research will focus on the unique mechanism by which TAG technology influences the emissivity and infrared rejection of surfaces, as well as further empirical application testing.

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