High temperature, optically transparent plastics from biomass

At a Glance

- Rapid, selective catalytic system to produce vinyl plastics from renewable biomass
- Stereoregular polymers with high T_g (up to 300 C) and outstanding resistance to heat, solvents, and scratching
- Patent pending synthesis to produce monomer for highest Tg plastic from cheap, bioderived itaconic acid
- Renewable alternative with performance advantages over petroleum-based polyacrylics such as pMMA
- Wide variety of applications, including optical fibers and heat/solvent resistant plastics

Details

Fabrication of polymers and plastics from naturally renewable feedstocks offers the potential for a cost effective and sustainable alternative to petroleum-based polymers. Biomass-derived vinyl polymers based on butyrolactone have been recognized as a potential substitute for plastics derived from petroleum-based polyacrylics, but catalytic systems suitable for large scale production have not yet been developed.

Researchers at Colorado State University have addressed this problem by developing a method to synthesize polymers from a class of renewable compounds, including α-methylene-*γ*-butyrolactone (MBL) and *γ*-methyl-α-methylene-*γ*-butyrolactone ($_{\gamma}$MMBL). The method uses a novel coordination polymerization system that incorporates a rare-earth metal (REM) catalyst. The polymerization system exhibits exceptional activity and proceeds at high speed. Furthermore, use of coordination polymerization allows for the synthesis of stereoregular polymers from racemic monomer solutions at room temperature (unprecedented in the case of $_{\beta}$MMBL).

In contrast with alternative systems based on radical polymerization, this coordination polymerization method yields stereoregular, isotactic polymer products with higher reaction rates and high conversion percentages. The resulting plastics (including PMBL, P$_{\gamma}$MMBL, and P$_{\beta}$MMBL) exhibit enhanced materials properties over the widely used poly(methyl methacrylate) (PMMA). In particular, they display high stereoregularity and excellent resistance to heat, solvents, and scratching, as well as extremely high glass-transition temperatures (T_g) of almost 300 C.

An innovative synthetic route to the β-monomer (also patent pending) has been developed that easily allows for the synthesis of 10's of grams from a very inexpensive starting material (itaconic acid, itself bioderived) via simple wet laboratory equipment and research-scale glassware. The method is expected to scale very well once quantities are required beyond what is needed for benchtop studies. The β-monomer is important as it leads to the bioplastic with the highest T_g.

The sustainability and advantageous properties exhibited by these materials make them excellent candidates to displace petroleum-based polymers based on methacrylates. The enhanced activity of the catalytic polymerization reaction and the efficient use of starting materials may make this a cost effective method to produce renewable, bio-derived plastics at large scale. The superior features of the resulting polymers may offer cost and performance advantages over petroleum-based polyacrylics in a number of applications, such as plastic optical fibers and any application requiring high heat and solvent resistance.

Common Questions

What is the utility of the invention? Engineering plastics from (ideally) biomass for high performance applications. Primary advantage identified so far is the extraordinarily high heat resistance of the material.

What stage of the development is the invention? Several catalyst systems have been developed and tested successfully at the laboratory bench scale. Characterization of plastics properties is preliminary but the heat properties have been demonstrated. A scalable method of producing the starting materials from itaconic acid has been developed. (Itaconic acid is an inexpensive, bioderived compound.)

Has a market for the invention identified? If so, what is the market for the invention? Several potential markets are possible. Leading candidates include use as optical fibers and optical lenses.

What are the next steps to move the invention toward commercialization? Technical next steps include demonstration of scale-up of reaction and further characterization of the plastics' properties. Marketing next steps are to identify specific applications that require our plastic and to identify strategic partners/licensees that supply these products.

What is the likely or logical commercialization path? (e.g. License or Startup?) If the invention is on the startup path, what stage of the development is the startup? Ultimately, commercialization is most likely going to require licensing to an existing company. However, in the interim, a startup company may be required in order to further develop technology and prove out the potential of the product (e.g., SBIR funding). The inventors are in the processing of forming this company.

What is the IP protection status? Multiple patents pending, including a PCT application.

Possible applications identified so far:

1) Plastic fiber optics. Preliminary characterization of our plastics indicates that their properties resemble those of PMMA, including the property of optical transparency. PMMA (aka Plexiglas, aka Lucite) has been used to some extent as the plastic in plastic optical fibers. Although the optical attenuation is not great, it is significant enough that typical fiber lengths are not usually greater than 50 or 100 feet. Nevertheless, plastic optical fibers have found some application and are often preferred on the basis of cost and/or weight.

   One significant drawback, however, is that their temperature resistance is not great. For instance, the industry standard sheathing used for fiber optic cables that are used in high stress situations requiring high reliability (e.g., aircraft) is known as Tefzel (Dupont's trade name) or ETFE ("poly(ethylene-co-tetrafluoroethylene)). This material must be extruded onto fiber optic cables at high temperature. To date, this has meant that it could only be applied to glass optical fibers as plastic fibers melt under the heat from the extruded ETFE. ***Our plastic will likely withstand the extrusion process and would enable the creation of ETFE-sheathed optical fibers for high stress/high reliability application.***

2) Plastic fiber launch optics. The lenses used to focus light from high intensity sources into fiber optics are currently almost exclusively glass lenses. To capture the light output with high efficiency, the launch optics must be located reasonably close to the light source, which is often operating at high temperature (e.g., metal halide lamps). Plastic lenses are unable to withstand such high heat. Even in the absence of infrared radiation (heat), particularly intense sources (e.g. LEDs) may produce enough visible light that even small levels of attenuation by the lens can cause warping from the heat stress induced by light absorption.

A drawback to glass lenses is their cost, due largely to the necessity to grind each glass lens. Plastic lenses due not suffer from this drawback as they are made using injection molding techniques. Our plastic may have sufficient temperature resistance as to be suitable for launch optics into optical fibers (irrespective of whether the fibers are glass or plastic). This is a particularly interesting application, as the cost of plastic lenses is primarily based on the cost of the mold. Materials costs are practically insignificant (if within reasonable bounds), which is of benefit as the monomers required by our technology will be significantly more expensive than those used to produce PMMA and other commodity plastics.

3) Encapsulation of photovoltaic devices. All or nearly all photovoltaic (PV) solar cell technologies require encapsulation with a transparent material, generally glass due to the high temperatures that PV cells typically experience when installed. Plastic encapsulation materials not only offer decreased cost and weight, but also offer the potential for flexible solar panels. Our high temperature plastic may be suitable as a lamination and/or encapsulation material for PV cells.

Note on the above applications:

In a conversation with a company that designs and sells remote source lighting (RSL) solutions, applications 1 & 2 identified above were confirmed. Such RSL solutions are valuable to ocean vessels, mining operations and other heavy equipment.

Note on processing from biomass:

The intent of the invention is to produce high value plastics from abundant biomass. However, the invention encompasses the polymerization of monomers that may be derived from biomass. ***Currently, these monomers need not be derived from biomass.*** In addition, we anticipate that a likely commercialization pathway may well proceed via a 2-step pathway. In step 1, applications for the resulting plastic are found and a market for these products is demonstrated. In this step, it may well be most expedient to utilize monomers derived from petroleum refining. In step 2, the infrastructure can be set up to produce the monomers from biomass. This should be easier once the need for the monomers/polymers is established in step 1. While it is possible that this infrastructure already exists, the use of our technology does not require it. Furthermore, although the infrastructure may not currently exist, the monomers chosen for this technology were specifically chosen because they may be derived from biomass.