The Polymer and the Hummingbird's Wing

Hummingbirds are unique and amazing birds: they can hover mid-air by rapidly flapping their wings. Even more amazing is the fact that an artificial polymer, which oscillates when exposed to laser light, can flutter like a hummingbird's wing.

What can a polymer have in common with a hummingbird's wing? It has been recently shown that a cantilever made of a photosensitive polymer can oscillate at high frequency when illuminated by a laser beam. Just like the oscillations of a hummingbird's wing, these oscillations occur at about thirty cycles per second (30 Hz). This effect was observed by the group lead by Timothy J. Bunning at the Research Laboratories at the Wright-Patterson Air Force Base (Ohio, USA).

Many molecules show sensitivity to light: azobenzene is one of them. Azobenzene is a chemical compound composed of two carbon rings linked together, in the shape of handcuffs, by a double bond between two nitrogen atoms. According to the position of the carbon rings in relation to the double bond, two configurations, or isomers, are possible for azobenzene molecules: the cis-isomer, when the rings are both on the same side in respect to the bond, and the trans-isomer when the rings are on opposite sides of the bond. One of the most intriguing properties of azobenzene is the photoisomeration of trans and cis isomers: the two isomers can be switched from one to the other with particular wavelengths of light, ultraviolet light for trans-to-cis conversion, and blue light for cis-to-trans isomerization.

The novelty in Bunning and colleagues' work is the ultrafast response of a cantilever made of azobenzene molecules embedded in a liquid crystal polymer network, when exposed to an ultraviolet laser beam. The polymeric cantilever bends towards the light source as a result of this exposure, and the momentum is such that it bends enough to expose its back side to the light radiation and then back again to expose its front side. Once turned on, this process repeats itself with high frequency, around 30 Hz.

The introduction of azobenzene molecules in liquid crystal networks, in particular, yields materials where light input can be converted into mechanical output [1]. "In our work the high frequency oscillations are enabled by the liquid crystalline nature of the polymer and the light source that we expose it with," Bunning points out. Indeed, "in the last ten years it has been shown that the inherent anisotropic order of liquid crystal polymers and networks amplifies the mechanical deformation of the system. Thus, small molecular changes induced by light via photoisomerization processes of azobenzene can be effectively magnified to enable large macroscopic photoinduced mechanical movements."

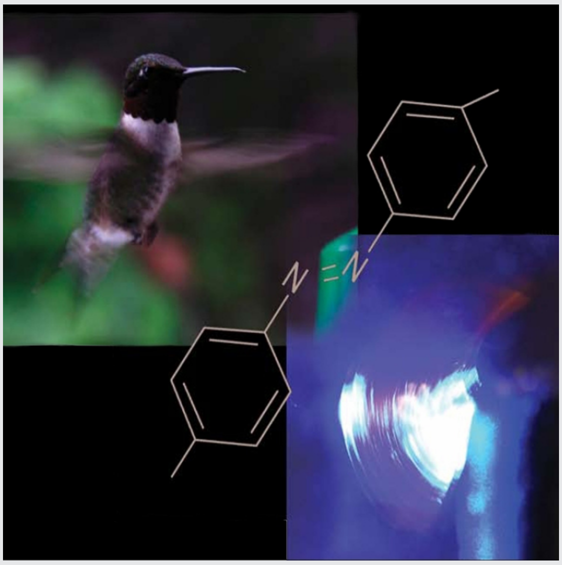

Figure 1: The polymeric hummingbird's wing. A polymeric cantilever containing photosensitive molecules (azobenzene, shown in the picture) starts to oscillate rapidly when exposed to light radiation. Just like the oscillations of a hummingbird's wing, these oscillations occur at about thirty cycles per second (30 Hz).

"The key properties of light enabling this effect," Bunning adds, "are polarization with respect to the polymer cantilever long axis, and intensity. Low intensity laser light does not induce these oscillations, as the cantilever does not deflect enough for the back surface to be exposed. The polarization of light is key once turned on, since azobenzene, the root of the photosensitive nature of the polymer, is dichroic in its absorbance." He goes on to explain that "these oscillations show on/off control as a response to the light polarization: indeed, the polymer cantilever oscillates to laser illumination when the polarization of the laser is parallel to the long axis of the cantilever, and it is static when the polarization is rotated ninety degrees."

"Visually, the observation causes one to imagine many applications, including the fluttering of a hummingbird's wing," Bunning prospects. "Essentially, any application wherein one wants to remotely actuate a material with a light source to enable a macroscopic mechanical effect (bending, twisting, rolling, buckling) might be envisioned." Bunning, nevertheless, cautions that "while the effect is certainly very interesting, applications are many years away. For the oscillations to occur and to be truly relevant, the threshold laser intensity must be reduced dramatically. Furthermore, engineering issues associated with miniaturization will need to be overcome."

Dick Broer at Philips Research Laboratories in Eindhoven (Netherlands) agrees that "this oscillatory phenomenon might introduce a number of new applications, such as beam steering for telecommunications, optically driven light shutters, soft actuators and artificial muscles, energy systems based on the conversion of sunlight into mechanical energy, as well as integrated elements in microfluidics to activate the pumping, mixing and controlling of flow direction." Moreover, Olivier Soppera at Université de Haute-Alsace (France) believes that "the main application may concern the fabrication of light driven micro-actuators useful for micro-manipulation purposes. The source of energy will no longer be electricity but light, making the design of such systems easier in terms of light and space requirements."

Soppera remarks that "one of the main issues could be the aging of the material: the authors claim that they could achieve hundreds of thousands of cycles but this may not be enough for practical applications." Broer adds that "to day the cantilevers are millimeter to centimeter sized: too big to be of interest for many applications, such as telecommunications and microfluidics. The next step will be to miniaturize these elements and to integrate them into devices. However, miniaturization might not be needed for a number of other applications, such as the designing of objects capable of flying."

[1] Y. Yu, M. Nakano and T. Ikeda, *Photomechanics: Directed bending of a polymer film by light*, Nature **425**, 145 (2003).

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