Express Polymer Letters Vol.20, No.7 (2026) 662–663
Available online at www.expresspolymlett.com
https://doi.org/10.3144/expresspolymlett.2026.49

Editorial corner – a personal view

Advancing space propulsion through polymer engineering

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Laser ablation propulsion (LAP) is a space propulsion technique based on generating an impulse on an object using a remotely located energy source. This is a promising strategy for the motion control of micro/nano-satellites and offers significant potential for space debris mitigation (https://doi.org/10.2514/1.43733).

Imagine a high-powered laser – stationed on the ground, on a high-altitude balloon, or mounted on an orbiting satellite – locking onto a piece of space junk. The laser fires intense, nanosecond pulses at the debris, instantly vaporizing a microscopic layer of its surface and converting it into a high- velocity plasma jet. This jet acts as a miniature rocket engine. By precisely timing these pulses, we can push the debris against its orbital velocity, causing it to slow down. This lowers its orbit and forces it into the dense upper atmosphere, where it burns up upon reentry. LAP is currently one of the most researched and promising solutions for cleaning up Earth's orbit (https://doi.org/10.1007/978-3-319-96845-2_8).

Various materials have been investigated as targets for LAP, including metals (https://doi.org/10.1063/5.0082109), carbon-based materials , and various polymers such as poly(vinyl chloride) (PVC) (http://dx.doi.org/10.1021/acs.jpcc.1c08175), polyoxymethylene (POM) (http://dx.doi.org/10.2514/1.32477) and poly(tetrafluoroethylene) (PTFE) (https://doi.org/10.1016/j.actaastro.2017.03.006).

Considerable research has been focused on maximizing the momentum coupling coefficient – the efficiency of the impulse generation process relative to the energy of the laser pulse. This is primarily achieved by optimizing the light-matter interaction through the addition of absorbers, such as carbon nanoparticles (https://doi.org/10.1007/s00339-023-06502-7).

Beyond developing specific laser-absorbing polymer composites, an alternative strategy to increase the momentum coupling coefficient is the spatial confinement of ablation products. This is achieved by cladding the target surface with a layer transparent to the wavelength of the laser. During irradiation, pressure increases significantly beneath this transparent coating. Once the pressure is sufficient to breach the confinement layer, the rapid ejection of the material generates an intense mechanical impulse. These confinement layers are typically glass or polymer sheets with thicknesses ranging from 0.1 to 1 mm. Using this configuration, researchers have demonstrated an enhancement of the impulse generated by aluminum by more than an order of magnitude (https://doi.org/10.1063/5.0225973).

A recently investigated strategy involves binary polymer blends, where the spontaneous segregation

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of carbonaceous particles into one of the two polymeric phases induces the in-situ formation of a confining layer during the ablation process. An example of this is the blend of poly(lactic acid) (PLA) and poly(1,12-dodecamethylene 2,5-furandicarboxylate) (PDoF) containing reduced graphene oxide (rGO), which segregates primarily into the PDoF phase (https://doi.org/10.1016/j.apsusc.2024.162251). In fact, the carbonaceous particles strongly interacts with the laser beam while the surrounding PLA phase acts as a confining transparent layer.

Polymer engineering clearly plays a critical role in developing advanced materials optimized for these specialized space applications.