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Review

Phase change materials in microactuators: Basics, applications and perspectives

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ABSTRACT

During the last decades micro electro mechanical systems (MEMS) have been subject to intensive research. In many cases active components, *e.g.*, for regulating fluid flow or generating movement need to be included in the system design to ensure controlled operation. However, conventional actuators can seldom be used because their efficiency decreases when their size is minimized. On the other hand miniaturization allows usage of a broad band of actuators that are inefficient in the macroscopic world. A significant amount of these actuators relies on phase change phenomena. The most intriguing fact about these transitions is their reversible nature which is associated to a pure physical transition. Facing an increasing amount of papers concerning phase change triggered micro actuation designers and operators of MEMS devices are often unable to decide which actuation principle is best-suited for their specific application. By summing up the content of more than 400 publications this review intends to provide designers as well as users of MEMS with the knowledge necessary for building efficient phase change driven actuators. For doing so the physical principles underlying each phase change phenomenon, which has been used for setting up MEMS, are introduced, followed by a thorough discussion of suitable materials that undergo the specific phase change. In order to enable the reader to choose the material best-suited for the target application the physical properties of more than 240 phase change materials, including some materials that have never been used in MEMS but are known from other research fields, *e.g.*, energy storage, are listed within the review. With a focus on the physical working principle, the review highlights actuator concepts which have been used as printer heads, valves, pumps, grippers, actuators in drug delivery devices, devices for endoscopic surgery, aerospace engineering, and several other applications. The features of these actuators are compared in comprehensible tables in order to allow operators to quickly decide which actuator they could use for their specific application.

Abbreviations: AAc, poly(acrylic acid); AuNP, gold nanoparticles; CF, carbon fibres; CFC, chlorinated/fluorinated hydrocarbons; DC, direct current; DES, deep eutectic solvents; DMSO, dimethyl sulfoxide; DES, deep eutectic solvents; DSC, differential scanning calorimetry; EDTA, ethylenediaminetetraacetic acid; ELISA, enzyme-linked immunosorbent assays; Eu, eutectic; GWP1, global warming potential; HBD, hydrogen bond donor; Ir, infrared; LidHCl, lidocaine hydrochloride; LoC, lab-on-a-chip; M, melt; MC, mixed crystals; MEMS, micro electro mechanical systems; NaPy, N-acryloylpyrrolidine; NIPAM, poly(N-Isopropylacrylamide); PAA, poly acrylic acid; PAAM, polyacrylamide; PCL, polycaprolactone; PCM, phase change materials; PCR, polymerase chain reaction; PDMAEMA, poly(N-(2-(dimethylamino) ethyl)-methacrylamide); PDMS, polydimethylsiloxane; PEG, polyethylene glycols; PEGDA, polyethylene glycol diacrylate; PHEMA, poly(2-hydroxyethyl methacrylate); PMAA, poly(methacrylic acid-choline chloride); poly((HEMA–AA)), poly(hydroxyethyl methacrylate acrylic acid); PVA, polyvinylalyohol; PVME, poly(vinylmethylether); RF, radio frequency; R-phase, rhombohedral phase; SMA, shape memory alloys; SMC, shape memory ceramics; SMP, shape memory polymers; T_{Af}, austenite finish temperature; $T_{g,s}$, glass transition start temperature; T_{Ms}, martensite start temperature; T_{Rs}, rombohedral start temperature; T_{Trans}, transition temperature; TBE, tris/borate/EDTA buffer; TRIS, tris-(hydroxymethyl)-aminomethane.

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Contents

1. Introduction

The usage of phase changes for transforming energy using a specific medium as translator is an old principle. Perhaps the most well-known example is the steam engine in which water is used to transfer thermal energy into mechanical energy. These traditional machines have been around for more than three hundred years now, therefore their working principles are well-known. However, recent progresses in material sciences and physics lead to a “real zoology of transitions” [1]. Thus the knowledge a scientist working in the field of phase change materials (PCM) has to have is no longer limited to the mere transitions of the state of matter. Understanding of gelation and mesomorphic transitions is also required. Furthermore, with the advent and maturation of micro-system technology new application scenarios for “phase change machines” emerged. Miniaturization allowed employing phase changes which would not have been deemed sufficiently effective in the macroscopic world. A lot of research has been done in this field and a huge selection of actuators applicable for valving, pumping, positioning, or on-demand release of substances have been developed. However, until today the time between the discovery of a new phase change material and the development of commercial devices, which use this material, is quite long. One of the main reasons for this is