

[0023] In a further embodiment, the molecular motor includes a first annular substrate defining at least one planar surface coated with a first motor protein and a second annular substrate defining at least one planar surface coated with a second motor protein that interacts with the first motor protein to move the second annular substrate relative to the first annular substrate. The annular substrate may be a thin disc or a ring. For example, the motor may include at least two layers of a plurality of concentric rings. One variant of the annular substrate embodiment includes a stationary substrate, a terminal annular substrate, and at least one intermediate annular substrate interposed between the stationary substrate and the terminal annular substrate. The stationary substrate, terminal annular substrate, and intermediate annular substrate are arranged such that each planar surface coated with a first motor protein is adjacent to a planar surface coated with a second motor protein. A second variant of the annular substrate embodiment includes a stationary member affixed to the first annular substrate and a rotatable member affixed to the second annular substrate wherein the first motor protein can interact with the second motor protein to move the second annular substrate relative to the first annular substrate and consequently rotate the rotatable member.

[0024] An additional molecular motor embodiment includes at least one continuous loop of a flexible substrate that defines at least two turning radii and at least one surface that is coated with a first motor protein. Rotation loci members are disposed at the turning radii and at least one of the rotation loci members defines a surface coated with a second motor protein. The interaction of the first motor protein and the second motor protein moves the flexible substrate relative to at least one of the rotation loci members.

[0025] The motor proteins can be attached to the surfaces in a variety of ways. The actin, for example, can be expressed by recombinant techniques as a fusion protein with a histidine tag, which is then attached to a nickel-coated surface. Alternatively, the actin can be expressed with an S-tag which binds to an S-protein coated surface, or with a streptavidin tag which binds to biotin on a substrate surface. In another specific, non-limiting example, gelsolin is used to attach the actin to a surface (e.g. see Suzuki et al., *Biophys. J.* 70:401-408, 1996).

[0026] In particular embodiments, the first motor protein (for example actin) is directionally attached on the outer surface of a rotatable cylinder or cone in an array that extends both longitudinally along and circumferentially around the tube or cone, and the second motor protein (such as myosin) extends both longitudinally along and circumferentially around the tube or cone in a complementary array of similar size.

[0027] The disclosure also describes a method of making a molecular motor, by providing a first continuous curved surface which rotates around a longitudinal axis, and a second curved surface which rotates around the longitudinal axis, and is complementary in shape to the first surface. Another method of making a molecular motor contemplates providing a first annular substrate defining a planar surface and a second annular substrate defining a planar surface, adhering a first motor protein to the planar surface of the first annular substrate and a second motor protein to the planar surface of the second annular substrate, and positioning the

first annular substrate relative to the second annular substrate so that the first motor protein can interact with the second motor protein to move the first annular substrate relative to the second annular substrate.

[0028] In the disclosed methods, a first motor protein (such as actin) is directionally adhered to the first surface, and a second motor protein (such as myosin) is adhered to the second surface, such that the first and second motor proteins interact to move the first and second surfaces relative to one another. In particular embodiments, the actin is adhered to the surface with a tag (for example a recombinantly expressed tag such as histidine, an S-tag or streptavidin) that interacts with a component of the first surface. The actin may be directionally applied to the planar or first curved surfaces by rotating the planar or curved surface in an actin containing solution.

[0029] In certain embodiments, the motor proteins can be portions of actin and myosin that are able to function to move the surfaces relative to one another. For example, heavy meromyosin or myosin I can be used instead of myosin II. In other embodiments, the motor proteins are microtubules and kinesin, or functional fragments thereof that are sufficient to move the surfaces. The kinesin can be, for example, the N-terminal 410 amino acid residues of kinesin.

[0030] The motor of the present disclosure may be a micromachined device constructed on a micrometer-scale, but the motor can also be constructed on a much larger scale by coating larger surfaces with the motor proteins, which can be purified from biological tissues (such as muscle) or produced in large quantities using recombinant techniques.

[0031] The molecular motors of the present disclosure are believed to operate much more efficiently than conventional engines that use large temperature differentials or magnetic fields to create rotary motion with energetic efficiencies less than about 35%. The Carnot efficiency of an internal combustion engine is 56%, but other losses reduce the efficiency to about 25%. Many such engines also depend on fossil fuels that create air pollution and may induce global warming as a consequence of the combustion of such fuels.

[0032] Muscles use contractile or motor molecules to create macroscopic motion with efficiencies near 70%, and the molecular motors of the present disclosure can use similarly efficient systems to create useful energy. This can be accomplished while producing substantially no pollution, because sugar (or ATP itself) could be used to fuel the motors, and the waste products (ADP and Pi) are biologically useful or biodegradable. In addition, the isothermal conditions under which the motor operates imply low materials stress, and easier construction and maintenance.

[0033] The biologically compatible nature of these devices also makes them suitable for medical applications. Biologically based engines can use sugar in the blood (via substrate level phosphorylation glycolysis) as fuel, to replace neuromuscular function lost to diseases such as myasthenia gravis or muscular dystrophy. Alternatively, the motor can be used to perform the mechanical functions of a prosthetic implant.

[0034] The foregoing and other objects, features, and advantages of the disclosed molecular motor will become