CLAIMS

1. A seal assembly for sealing within an annulus between inner and outer coaxially disposed annular members having a common axis, the seal assembly comprising:

a first anti-extrusion sealing ring having a chevron shaped geometry;

a second anti-extrusion sealing ring having a chevron shaped geometry, the second anti-extrusion sealing ring coaxial with and axially below the first anti-extrusion sealing ring;

a first compliant sealing ring having a chevron shaped geometry, the first compliant sealing ring coaxial with and interposed between the first anti-extrusion sealing ring and the second anti-extrusion sealing ring;

wherein at least one of the first and second anti-extrusion sealing rings is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force; and

the first compliant sealing ring is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force.

2. The seal assembly of Claim 1, further comprising:

a spring axially aligned with the first and second anti-extrusion sealing rings and the compliant sealing ring; and

wherein the spring maintains an axial force on the first and second anti-extrusion sealing ring and the first complaint sealing ring, thereby maintaining a radial force between the sealing rings and the inner and outer annular members.

3. The seal assembly of Claim 1 or Claim 2, further comprising:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings;

a second compliant sealing ring having a chevron shaped geometry, the second compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring; and

wherein the first and second anti-extrusion sealing rings face in a first axial direction, and the third and fourth anti-extrusion sealing rings face in a second axial direction, opposite the first axial direction, thereby forming a bi-directional seal when energized.

4. The seal assembly of any preceding Claim, wherein the first compliant sealing ring comprises a material having a modulus of elasticity no greater than half of the modulus of elasticity of the first and second anti-extrusion rings.

5. The seal assembly of any preceding Claim, wherein:

the first and second anti-extrusion sealing rings are formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof; and

the first compliant sealing ring is formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof.

6. The seal assembly of any preceding Claim, further comprising:

an upper activation ring coaxial with and axially above the first anti-extrusion ring, the upper activation ring having a lower mating surface forming an angle to the axis different from the adjacent surface of the first anti-extrusion ring;

a lower activation ring coaxial with and axially below the second anti-extrusion ring, the lower activation ring having an upper mating surface forming an angle to the axis different from the adjacent surface of the second anti-extrusion ring;

wherein mating surfaces between the first anti-extrusion ring and the first compliant ring are at equivalent angles to the axis, allowing the first anti-extrusion ring and the first compliant ring to contact along the length of the mating surfaces;

wherein mating surfaces between the second anti-extrusion ring and the first compliant ring are at equivalent angles to the axis, allowing the second anti-extrusion ring and the first compliant ring to contact along the length of the mating surfaces; and

wherein under axial load, contact between the upper and lower activation ring mating surfaces with adjacent anti-extrusion sealing ring mating surfaces causes radial expansion of the first and second anti-extrusion sealing rings and the compliant sealing ring.

7. The seal assembly of any preceding Claim, wherein the angles of the mating surfaces between the first anti-extrusion sealing ring, the second anti-extrusion ring, and the compliant ring cause an increase in sealing pressure in response to increased pressure within the annulus.

8. The seal assembly of any preceding Claim, further comprising:

the first anti-extrusion sealing ring having a lower mating surface forming an angle to the axis that is different than an angle formed by a mating surface of the adjacent compliant sealing ring to the axis;

the second anti-extrusion sealing ring having an upper mating surface forming an angle to the axis that is different than an angle formed by a mating surface of the adjacent compliant sealing ring to the axis; and

wherein under axial load, contact between the mating surfaces causes radial expansion of the first and second anti-extrusion sealing rings and the compliant sealing ring.

9. The seal assembly of any preceding Claim, wherein at least one of the angles of the first anti-extrusion sealing ring mating surface and the second anti-extrusion ring surface causes an increase in sealing pressure in response to increased pressure within the annulus.

10. The seal assembly of any preceding Claim, further comprising:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings, and axially below the third anti-extrusion sealing ring;

a second compliant sealing ring having a chevron shaped geometry, the compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring;

wherein the third and fourth anti-extrusion sealing rings have an outer diameter smaller than an inner diameter of the first and second anti-extrusion sealing rings;

wherein outer diameter surfaces of at least one of the first and second anti-extrusion sealing rings seal to the outer annular member when energized;

wherein outer diameter surfaces of the first compliant sealing ring seal to the outer annular member when energized;

wherein inner diameter surfaces of at least one of the third and fourth anti-extrusion sealing rings seal to the inner annular member when energized; and

wherein inner diameter surfaces of the second compliant sealing ring seal to the inner annular member when energized.

11. The seal assembly of any preceding Claim, the seal assembly further comprising:

a seal retainer ring comprising an annular member defining inner and outer annular upward facing shoulders separated by a cylindrical member coaxial with the axis;

wherein the seal retainer ring removably couples to a running tool for insertion of and removal of the seal assembly;

wherein the first and second anti-extrusion sealing rings and the first compliant sealing ring mount to the outer upward facing shoulder of the seal retainer ring; and

wherein the third and fourth anti-extrusion sealing rings and the second compliant ring mount to the inner upward facing shoulder of the seal retainer ring.

12. A seal assembly for sealing within an annulus between inner and outer coaxially disposed annular members having a common axis, the seal assembly comprising:

a seal stack;

an upper activation ring coaxial with and axially above the seal stack, the upper activation ring having a lower mating surface forming an angle to the axis different from the adjacent surface of the seal stack;

a lower activation ring coaxial with and axially below the seal stack, the lower activation ring having an upper mating surface forming an angle to the axis different from the adjacent surface of the seal stack;

wherein mating surfaces between elements of the seal stack are at equivalent angles to the axis, allowing the elements to contact the along the length of the mating surfaces; and

wherein under axial load contact between the upper and lower activation ring mating surfaces with adjacent seal stack mating surfaces causes radial expansion of the seal stack.

13. The seal assembly of Claim 12, further comprising:

a spring axially aligned with the seal stack; and

wherein the spring maintains an axial force on the seal stack, thereby maintaining a radial force between the seal stack and the inner and outer annular members.

14. The seal assembly of Claim 12 or Claim 13, wherein the seal stack comprises:

a first anti-extrusion sealing ring having a chevron shaped geometry;

a second anti-extrusion sealing ring having a chevron shaped geometry, the second anti-extrusion sealing ring coaxial with and axially below the first anti-extrusion sealing ring;

a first compliant sealing ring having a chevron shaped geometry, the first compliant sealing ring coaxial with and interposed between the first anti-extrusion sealing ring and the second anti-extrusion sealing ring;

wherein at least one of the first and second anti-extrusion sealing rings is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force; and

the first compliant sealing ring is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force.

15. The seal assembly of any of Claims 12 to 14, wherein the seal stack further comprises:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings, and axially below the third anti-extrusion sealing ring;

a second compliant sealing ring having a chevron shaped geometry, the second compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring; and

wherein the first and second anti-extrusion sealing rings face in a first axial direction, and the third and fourth anti-extrusion sealing rings face in a second axial direction, opposite the first axial direction, thereby forming a bi-directional seal when energized.

16. The seal assembly of any of Claim 12 to 15, wherein the first compliant sealing ring comprises a material having a modulus of elasticity no greater than half of the modulus of elasticity of the first and second anti-extrusion rings.

17. The seal assembly of any of Claims 12 to 16, wherein:

the first and second anti-extrusion sealing rings are formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof; and

the first compliant sealing ring is formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof.

18. The seal assembly of any of Claims 12 to 17, further comprising:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings, and axially below the third anti-extrusion sealing ring;

a second compliant sealing ring having a chevron shaped geometry, the second compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring;

wherein the third and fourth anti-extrusion sealing rings have an outer diameter smaller than an inner diameter of the first and second anti-extrusion sealing rings;

wherein outer diameter surfaces of at least one of the first and second anti-extrusion sealing rings seal to the outer annular member when energized;

wherein outer diameter surfaces of the first compliant sealing ring seal to the outer annular member when energized;

wherein inner diameter surfaces of at least one of the third and fourth anti-extrusion sealing rings seal to the inner annular member when energized; and

wherein inner diameter surfaces of the second compliant sealing ring seal to the inner annular member when energized.

19. The seal assembly of any of Claims 12 to 18, the seal assembly further comprising:

a seal retainer ring comprising an annular member defining inner and outer annular upward facing shoulders separated by a cylindrical member coaxial with the axis;

wherein the seal retainer ring removably couples to a running tool for insertion of and removal of the seal assembly;

wherein the first and second anti-extrusion sealing rings and the first compliant sealing ring mount to the outer upward facing shoulder of the seal retainer ring; and

wherein the third and fourth anti-extrusion sealing rings and the second compliant ring mount to the inner upward facing shoulder of the seal retainer ring.

20. A seal assembly for sealing within an annulus between inner and outer coaxially disposed annular members having a common axis, the seal assembly comprising:

a first seal stack having an inner diameter;

the first seal stack having compliant sealing elements that, when energized, seal to a damaged surface of the outer annular member;

a second seal stack coaxial with the first seal stack, the second seal stack having an outer diameter smaller than the inner diameter of the first seal stack; and

the second seal stack having compliant sealing elements that, when energized, seal to a damaged surface of the inner annular member.

21. The seal assembly of Claim 20, the seal assembly further comprising:

a seal retainer ring comprising an annular member defining inner and outer annular upward facing shoulders separated by a cylindrical member coaxial with the axis;

wherein the seal retainer ring removably couples to a running tool for insertion and removal of the first and second seal stack;

wherein the first seal stack mounts to the outer upward facing shoulder of the seal retainer ring; and

wherein second seal stack mounts to the inner upward facing shoulder of the seal retainer ring.

22. The seal assembly of Claim 20 or Claim 21, wherein the first and second seal stacks each comprise:

a first anti-extrusion sealing ring having a chevron shaped geometry;

a second anti-extrusion sealing ring having a chevron shaped geometry, the second anti-extrusion sealing ring coaxial with and axially below the first anti-extrusion sealing ring;

a first compliant sealing ring having a chevron shaped geometry, the first compliant sealing ring coaxial with and interposed between the first anti-extrusion sealing ring and the second anti-extrusion sealing ring;

wherein at least one of the first and second anti-extrusion sealing rings is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force; and

the first compliant sealing ring is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force.

23. The seal assembly of any of Claims 20 to 22, wherein the compliant sealing ring comprises a material having a modulus of elasticity no greater than half of the modulus of elasticity of the first and second anti-extrusion rings.

24. The seal assembly of any of Claims 20 to 23, wherein:

the first and second anti-extrusion sealing rings are formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof; and

the compliant sealing ring is formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof.

25. The seal assembly of any of Claims 20 to 24, wherein the first and second seal stacks each further comprise:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings;

a second compliant sealing ring having a chevron shaped geometry, the second compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring; and

wherein the first and second anti-extrusion sealing rings face in a first axial direction, and the third and fourth anti-extrusion sealing rings face in a second axial direction, opposite the first axial direction, thereby forming a bi-directional seal when energized.

26. The seal assembly of any of Claims 20 to 25, further comprising:

a spring axially aligned with the first and second seal stacks; and

wherein the spring maintains an axial force on the first and second seal stacks, thereby maintaining a radial force between the first and second seal stacks and the inner and outer annular members.

27. A method for sealing within an annulus between inner and outer coaxially disposed annular members having a common axis, the method comprising:

(a) providing a sealing ring;

(b) coupling a locking ring to the sealing ring;

(c) axially moving an energizing ring in a first direction with a setting tool to apply an axial force to the locking ring, which in turn acts on the sealing ring to radially deform the sealing ring into sealing engagement with the annular members; and

(d) continuing axial movement of the locking ring in the first direction to radially deform the locking ring into locking engagement with the annular members.

28. The method of Claim 27, wherein step (b) comprises applying an axial force to the sealing ring.

29. The method of Claim 27 or Claim 28, wherein step (b) comprises placing the sealing ring on an upward facing surface in a seal pocket between the inner and outer members after the locking ring is coupled to the sealing ring and before step (c).

30. A seal assembly substantially as hereinbefore described with reference to the accompanying drawings.

31. A method substantially as hereinbefore described with reference to the accompanying drawings.

CLAIMS

1. A seal assembly for sealing within an annulus between inner and outer coaxially disposed annular members having a common axis, the seal assembly comprising:

a first anti-extrusion sealing ring having a chevron shaped geometry;

a second anti-extrusion sealing ring having a chevron shaped geometry, the second anti-extrusion sealing ring coaxial with and axially below the first anti-extrusion sealing ring;

a first compliant sealing ring having a chevron shaped geometry, the first compliant sealing ring coaxial with and interposed between the first anti-extrusion sealing ring and the second anti-extrusion sealing ring, the first compliant sealing ring comprising a material having a modulus of elasticity no greater than half of the modulus of elasticity of the first and second anti-extrusion rings;

wherein at least one of the first and second anti-extrusion sealing rings is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force; and

the first compliant sealing ring is configured to radially engage at least one of the inner and outer coaxially disposed annular members when subjected to an axial force.

2. The seal assembly of Claim 1, further comprising:

a spring axially aligned with the first and second anti-extrusion sealing rings and the compliant sealing ring; and

wherein the spring maintains an axial force on the first and second anti-extrusion sealing ring and the first complaint sealing ring, thereby maintaining a radial force between the sealing rings and the inner and outer annular members.

3. The seal assembly of Claim 1 or Claim 2, further comprising:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings;

a second compliant sealing ring having a chevron shaped geometry, the second compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring; and

wherein the first and second anti-extrusion sealing rings face in a first axial direction, and the third and fourth anti-extrusion sealing rings face in a second axial direction, opposite the first axial direction, thereby forming a bi-directional seal when energized.

4. The seal assembly of any preceding Claim, wherein:

the first and second anti-extrusion sealing rings are formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof; and

the first compliant sealing ring is formed from materials selected from the group consisting of metals, polymers, elastomers, ceramics, and composites thereof.

5. The seal assembly of any preceding Claim, further comprising:

an upper activation ring coaxial with and axially above the first anti-extrusion ring, the upper activation ring having a lower mating surface forming an angle to the axis different from the adjacent surface of the first anti-extrusion ring;

a lower activation ring coaxial with and axially below the second anti-extrusion ring, the lower activation ring having an upper mating surface forming an angle to the axis different from the adjacent surface of the second anti-extrusion ring;

wherein mating surfaces between the first anti-extrusion ring and the first compliant ring are at equivalent angles to the axis, allowing the first anti-extrusion ring and the first compliant ring to contact along the length of the mating surfaces;

wherein mating surfaces between the second anti-extrusion ring and the first compliant ring are at equivalent angles to the axis, allowing the second anti-extrusion ring and the first compliant ring to contact along the length of the mating surfaces; and

wherein under axial load, contact between the upper and lower activation ring mating surfaces with adjacent anti-extrusion sealing ring mating surfaces causes radial

expansion of the first and second anti-extrusion sealing rings and the first compliant sealing ring.

6. The seal assembly of any preceding Claim, wherein the angles of the mating surfaces between the first anti-extrusion sealing ring, the second anti-extrusion ring, and the first compliant ring cause an increase in sealing pressure in response to increased pressure within the annulus.

7. The seal assembly of any preceding Claim, further comprising:

the first anti-extrusion sealing ring having a lower mating surface forming an angle to the axis that is different than an angle formed by a mating surface of the adjacent first compliant sealing ring to the axis;

the second anti-extrusion sealing ring having an upper mating surface forming an angle to the axis that is different than an angle formed by a mating surface of the adjacent first compliant sealing ring to the axis; and

wherein under axial load, contact between the mating surfaces causes radial expansion of the first and second anti-extrusion sealing rings and the first compliant sealing ring.

8. The seal assembly of Claim 7, wherein at least one of the angles of the first anti-extrusion sealing ring mating surface and the second anti-extrusion ring surface causes an increase in sealing pressure in response to increased pressure within the annulus.

9. The seal assembly of any preceding Claim, further comprising:

a third anti-extrusion sealing ring having a chevron shaped geometry, the third anti-extrusion sealing ring coaxial with the first and second anti-extrusion sealing rings;

a fourth anti-extrusion sealing ring having a chevron shaped geometry, the fourth anti-extrusion sealing ring coaxial with the first, second, and third anti-extrusion sealing rings, and axially below the third anti-extrusion sealing ring;

a second compliant sealing ring having a chevron shaped geometry, the compliant sealing ring coaxial with and interposed between the third anti-extrusion sealing ring and the fourth anti-extrusion sealing ring;

wherein the third and fourth anti-extrusion sealing rings have an outer diameter smaller than an inner diameter of the first and second anti-extrusion sealing rings;

wherein outer diameter surfaces of at least one of the first and second anti-extrusion sealing rings seal to the outer annular member when energized;

wherein outer diameter surfaces of the first compliant sealing ring seal to the outer annular member when energized;

wherein inner diameter surfaces of at least one of the third and fourth anti-extrusion sealing rings seal to the inner annular member when energized; and

wherein inner diameter surfaces of the second compliant sealing ring seal to the inner annular member when energized.

10. The seal assembly of Claim 9, the seal assembly further comprising:

a seal retainer ring comprising an annular member defining inner and outer annular upward facing shoulders separated by a cylindrical member coaxial with the axis;

wherein the seal retainer ring removably couples to a running tool for insertion of and removal of the seal assembly;

wherein the first and second anti-extrusion sealing rings and the first compliant sealing ring mount to the outer upward facing shoulder of the seal retainer ring; and

wherein the third and fourth anti-extrusion sealing rings and the second compliant ring mount to the inner upward facing shoulder of the seal retainer ring.

11. A method for sealing within an annulus between inner and outer coaxially disposed annular members having a common axis, the method comprising:

(a) providing a seal assembly according to any one of the preceding claims within the annulus;

(b) coupling a locking ring to the seal assembly;

(c) axially moving an energizing ring in a first direction with a setting tool to apply an axial force to the locking ring, which in turn acts on the seal assembly to radially deform the seal assembly into sealing engagement with the annular members; and

(d) continuing axial movement of the locking ring in the first direction to radially deform the locking ring into locking engagement with the annular members.

12. The method of Claim 11, wherein step (b) comprises applying an axial force to the seal assembly.

13. The method of 11 or Claim 12, wherein step (b) comprises placing the seal assembly on an upward facing surface in a seal pocket between the inner and outer members after the locking ring is coupled to the seal assembly and before step (c).

14. A seal assembly substantially as hereinbefore described with reference to the accompanying drawings.

15. A method substantially as hereinbefore described with reference to the accompanying drawings.