

WHAT IS CLAIMED IS:

1. A method for forming a metal foil capacitor, comprising:
 - (a) providing a metal substrate;
 - (b) modifying the metal substrate to generate a porous thin film on the metal substrate;
 - (c) forming a dielectric layer on the porous thin film of the metal substrate;
 - (d) depositing a cathode layer conformal with the dielectric layer using atomic layer deposition or using electroless deposition; and
 - (e) depositing a metal layer on the cathode layer using electroless deposition to form the metal foil capacitor.
2. The method of claim 1, wherein the metal substrate comprises aluminum.
3. The method of claim 1, wherein (b) comprises physical vapor deposition (PVD), chemical vapor deposition (CVD), glancing angle deposition (GLAD), or etching.
4. The method of claim 1, wherein (c) comprises depositing the dielectric layer on the porous thin film of the metal substrate using atom layer deposition.
5. The method of claim 1, wherein (c) comprises anodizing the porous thin film of the metal substrate.
6. The method of claim 1, wherein the dielectric layer comprises alumina.
7. The method of claim 6, wherein the dielectric layer further comprises an oxide of titanium (Ti), silicon (Si), zinc (Zn), zirconium (Zr), tantalum (Ta), hafnium (Hf), lanthanum (La), yttrium (Y), strontium (St), or a combination thereof.
8. The method of claim 1, wherein the metal layer comprises one or more of nickel (Ni), copper (Cu), silver (Ag), or aluminum (Al).
9. The method of claim 1, wherein a dielectric constant (k) of the metal foil capacitor is at least 5.
10. The method of claim 1, wherein the dielectric constant (k) is at least 10.

11. The method of claim 1, wherein the metal substrate or the porous thin film comprises at least 0.01% by weight of an additional metal.
12. The method of claim 11, wherein the additional metal is titanium (Ti), silicon (Si), zinc (Zn), zirconium (Zr), tantalum (Ta), hafnium (Hf), lanthanum (La), yttrium (Yt), or strontium (St).
13. The method of claim 1, wherein the additional metal is present from 0.01 to 30 wt.%, based on the total weight of the metal substrate.
14. The method of claim 1, wherein the dielectric layer is at most 100 nanometers thick.
15. The method of claim 1, wherein the metal foil capacitor has an average capacitance of at least $1 \mu\text{F}/\text{mm}^2$.
16. The method of claim 1, wherein the metal foil capacitor has a capacitance of at least about $1.8 \mu\text{F}/\text{mm}^2$ at 100 kHz.
17. The method of claim 1, wherein the cathode layer comprises titanium nitride.