**Setup process for CNT Forest Synthesis**

1. **Known knowledge:**
   1. **Thresholds for Density, Diameter and Height:**
      1. A CNT is regarded dense if the density > 10^9 CNT/cm^2
      2. Diameter of a CNT < 10 nm
      3. A CNT forest is tall if height > 100 micrometers
   2. **Methods of measuring height:**
      1. System with 20 μm resolution: system can detect height changes as small as 20.
      2. Laser reflectivity with 10 nm resolution: can measure the height with finer precision down to 10 nm.
   3. **Elastic Modulus (Mechanical strength) of Individual CNT V/S CNT Forest**
      1. Individual CNT: 1 TPa (terapascal)
      2. CNT Forest: 1 MPa to 100 MPa
   4. The **tensile force** required to detach CNTs from substrates based on simulation is between 3-12 nN (nanonewtons).
   5. **Temperature:**
      1. A high synthesis temperature > 600 degrees Celsius
2. **Equipment and Materials:**
   1. **Scanning Electron Microscope (SEM)**:
      1. Model: FEI Quanta 600F
      2. Stage: Protochips Fusion 350 SEM stage
   2. **Heating Substrate**:
      1. Type: MEMS-based heating substrate
      2. Size: 50 × 50 μm area with a 3 x 3 array of holes
   3. **Gase Used**:
      1. Acetylene (C2H2)
   4. **Materials for Catalyst Preparation**:
      1. Aluminum oxide (Al2O3)**:** 10 nm
      2. Iron (Fe): 2 nm
3. **Sample Preparation**
   1. **Plasma Treatment**
      1. Heating substrate is plasma treated using glow discharge.
      2. **Parameters:**
         * Pressure: 2500 Pa
         * Current: 15 μA
         * Duration: 5 minutes
   2. **Catalyst Deposition**
      1. Catalyst film stack is created on the substrate
      2. **Materials**:
         * 10 nm of aluminum oxide deposited first
         * 2 nm of iron deposited on top
      3. **Method**:
         * Ion-beam sputtering
      4. **Base Pressure:**
         * Pa during deposition
4. **ESEM (Environmental Scanning Electron Microscope) Setup**
   1. **Chamber Preparation**
      1. The ESEM chamber with the substrate is pumped overnight for approximately 15 hours to achieve a low chamber pressure of Pa.
      2. A cold finger system captures volatile impurities and water vapor.
      3. The cold finger is filled with a slurry of dry ice and acetone for cooling
   2. **Gas Purging:**
      1. Initially, the SEM chamber is purged with acetylene gas, cycling the pressure between 10 and 150 Pa for three cycles.
      2. Acetylene is then supplied continuously at 5 psi (34,400 Pa) to the ESEM
   3. **Temperature Control:**
      1. Heating is applied at a constant rate of 15 °C per second from ambient temperature to the synthesis temperature of 625 °C.
   4. **Image Capturing:**
      1. Images of the CNT growth are captured at a rate of 30 frames per minute.

**Results and observations for CNT Forest Synthesis**

1. **Catalyst Reduction:**
   1. An iron thin film serves as the catalyst, which undergoes reduction to form discrete nanoparticles necessary for CNT growth.
   2. Carbon is deposited onto specific substrate areas using electron beam rastering, creating patterns that aid in iron film reduction.
   3. Carbon can be introduced in gaseous (acetylene) or solid forms, resulting in effective reduction of the iron film.
2. **Process:**
   1. The electron beam scans targeted regions for up to 20 minutes, which results in varying levels of carbon deposition that are visible as dark squares in SEM imagery.
   2. The substrate is heated to 550 °C for nanoparticle formation, which is below the CNT synthesis temperature of 625 °C.
   3. Iron nanoparticles become visible as bright particles post-heating, which means the reduction process was successful.
3. **CNT Growth Observations:**
   1. **Growth**:
      1. CNTs grow in vertical pillars
      2. Dense CNT forests, or micropillars, form from carbon deposition, with some exceeding heights of 100 μm.
      3. Individual CNTs are visible at: high magnifications (50,000 to 100,000)
      4. CNT Forests are visible at: lower magnifications (10,000)
      5. Growth Mechanism: CNTs follow a base-growth mechanism where iron nanoparticles remain on the substrate, allowing for upward growth.
      6. Nucleation and early growth: CNTs nucleate from iron nanoparticles about 10 seconds after reaching 575 °C, initially growing in an arched morphology.
   2. **Carbon Dosage:** 
      1. Growth height varies with carbon dosage.
      2. Higher doses (10-20 minutes) result in robust growth.
      3. Lower doses (5 minutes) result in sparse growth
4. **Unsuccessful attempts:**
   1. An attempt to grow CNTs is unsuccessful when the patterned carbon yield is either sparse or no CNT growth.