Nano Sensors

PhD/ MTech/ BTech

Course No.: EEL7450

L-T-P [C]: 3–0–0 [3]

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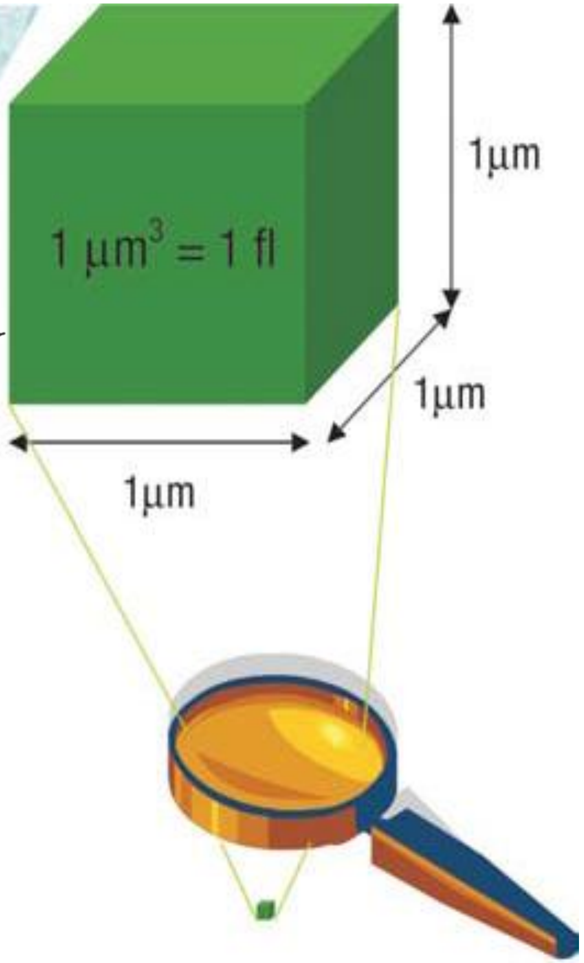
Fluids at Nanoscale

Microfluidics deals with the behaviour, control & manipulation of fluids that are typically in:

- **small volumes (nL, pL, fL)**
- **small size**
- **low energy consumption**
- **effects of the micro domain**

Downscaling of volumes

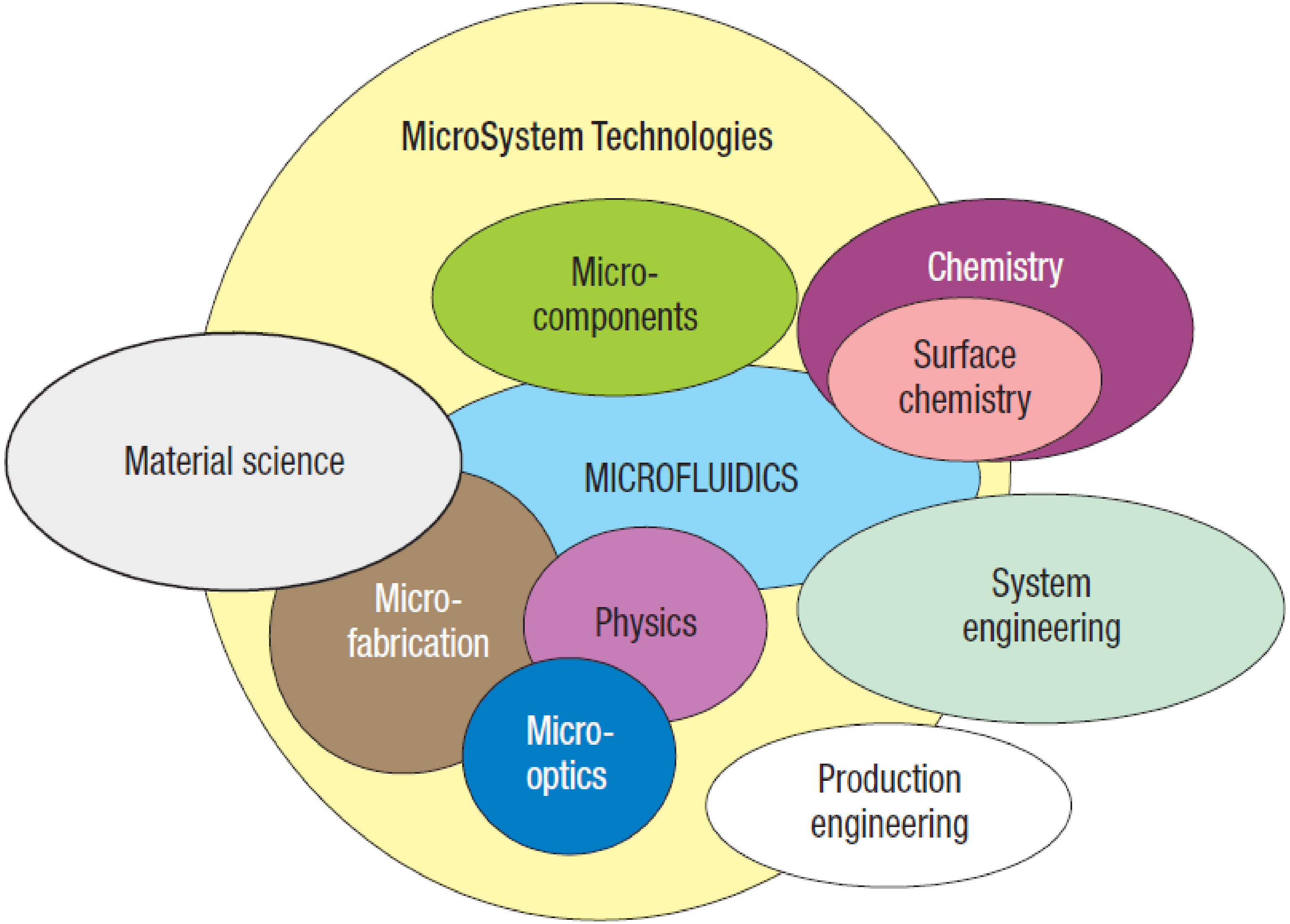
Litres	l	1
Decilitres	dl	10^{-1}
Centilitres	cl	10^{-2}
Millilitres	ml	10^{-3}
Microlitres	**µl**	10^{-6}
Nanolitres	**nl**	10^{-9}
Picolitres	**pl**	10^{-12}
Femtolitres	**fl**	10^{-15}
Attolitres	al	10^{-18}



$1\ cm^3 = 1\ mL$

Microfluidics is interdisciplinary

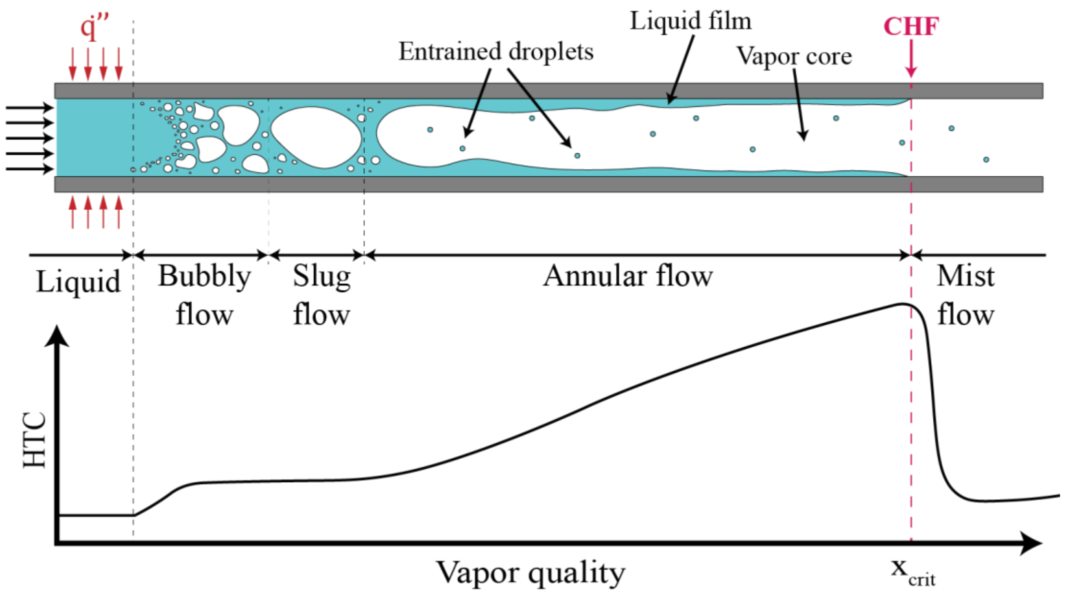
- related with various Science & Engineering areas



Micro to Nano Fluidics

- When fluids flow in nano-scale, the flow in non-continuous
- Nanofluids are dispersions of nanomaterials in base fluids
  - nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets.
- Nanofluids have some unique features that are quite different from dispersions of mm or μm sized particles.
- Compared to conventional cooling liquids such as water, kerosene, ethylene glycol and microfluids, nanofluids have been shown to exhibit higher thermal conductivities.
- Nanofluids do not block flow channels and induces only a very small pressure drop during flow - beneficial for heat transfer applications

- Three properties that make nanofluids promising coolants are
  - the increased thermal conductivity,
  - the increased heat transfer, and
  - the increased critical heat flux.
- The more efficient heat transfer from the heated surface is due to heat of vaporization & sensible heat.



Flow boiling regime progression (top) and qualitative description of heat transfer (bottom).

- It is observed that small amounts of nanoparticles can enhance thermal conductivity of base fluids to a large extent.

Applications of nanofluids:

(a) heat transfer,

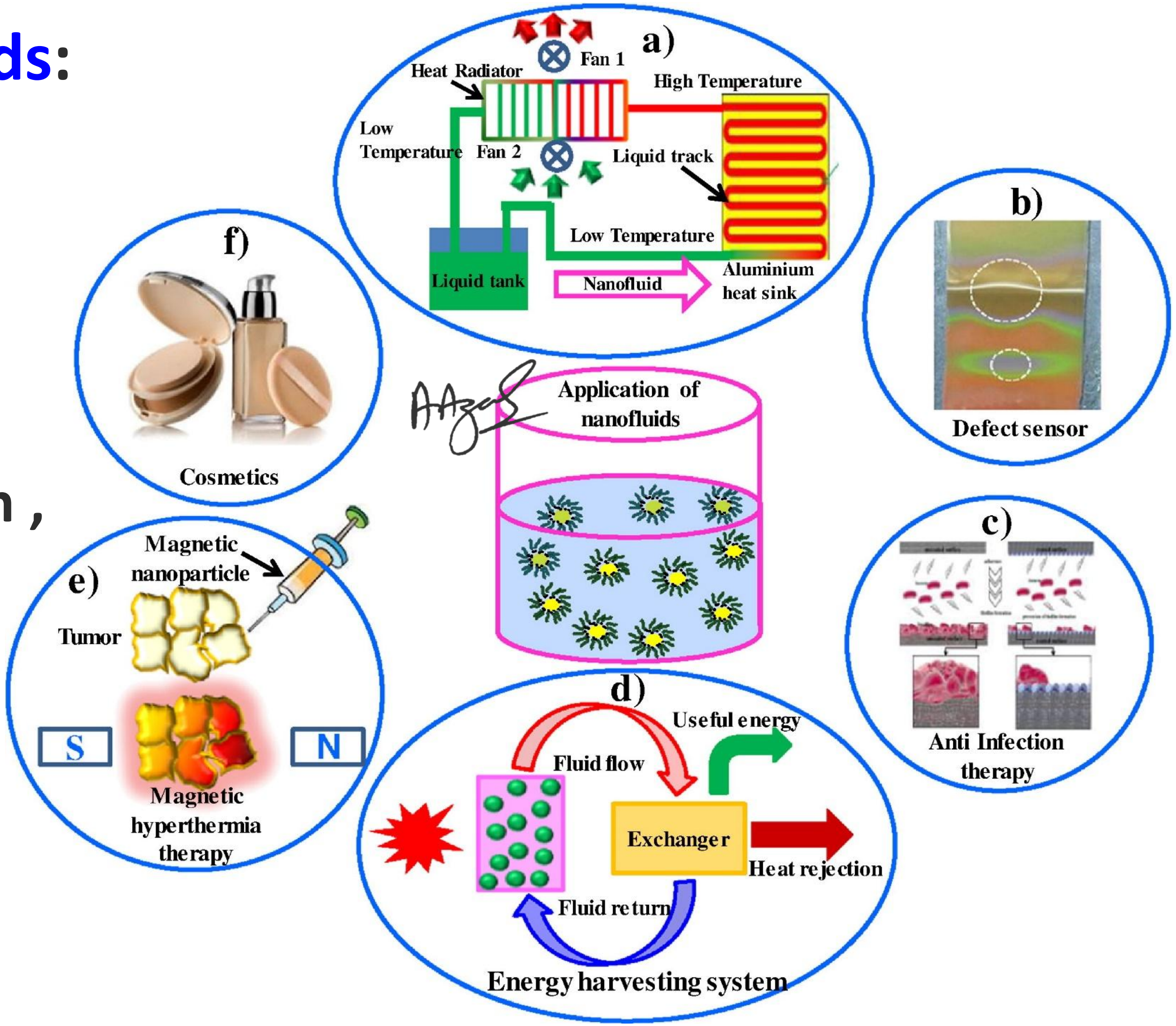
(b) defect sensors,

(c) anti infection therapy,

(d) energy harvesting system ,

(e) hyperthermia and

(f) cosmetics



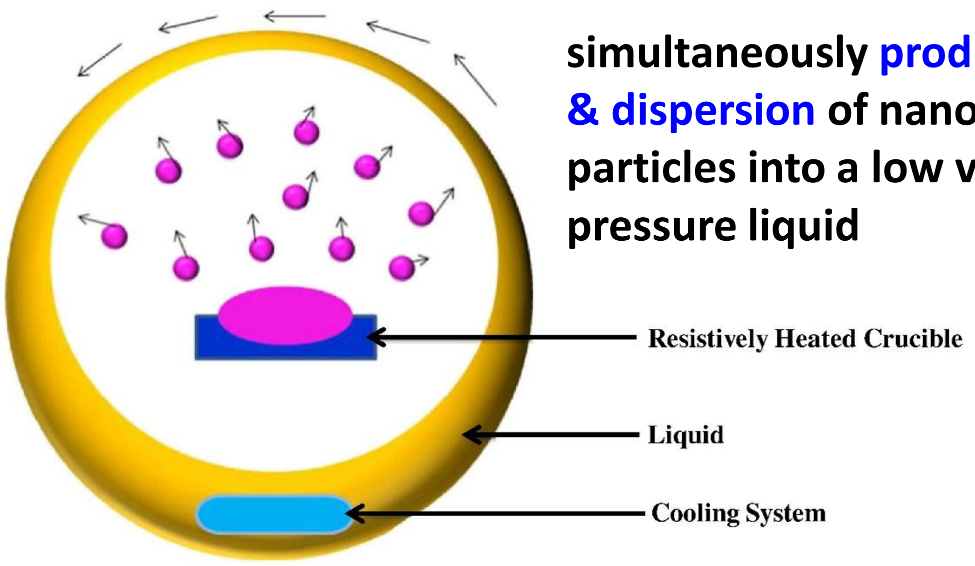
Questions/ Discussion

Preparation of nanofluids

- Nanofluids are prepared by one step or two step method.
- In **one-step** method, the production of nanoparticles and their dispersion in a base fluid are done simultaneously.
- In these methods, the drying, storage, transportation, and dispersion of nanoparticles are not required & hence the agglomeration of nanoparticles can be minimized, and the stability of fluids can be increased.
- The disadvantage in the one-step method is that the residual reactants (impurities) are left in the nanofluids due to the incomplete reaction, which are difficult to remove.

The one step processes used to prepare nanofluids:

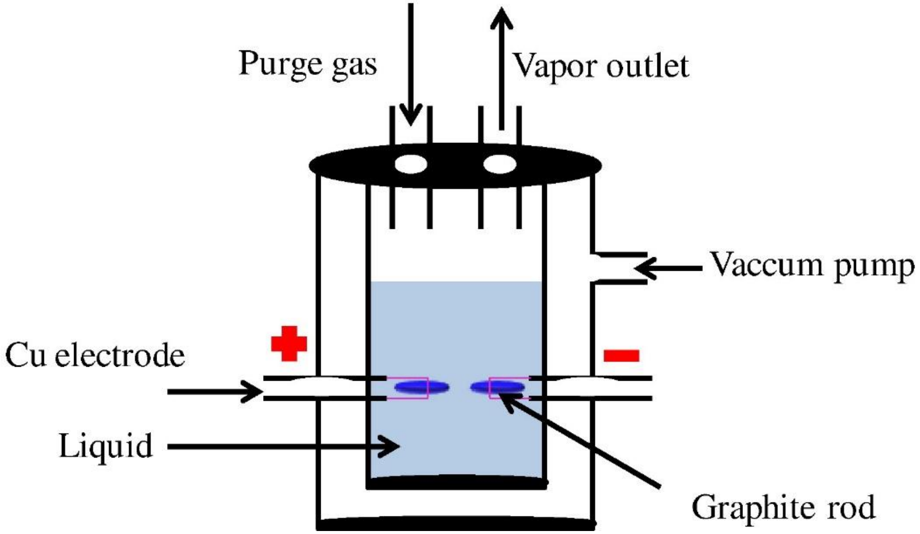
1. **Direct evaporation technique**: the direct evaporation & condensation of the nano-particulate materials in base liquid are obtained to produce stable nanofluids



simultaneously production & dispersion of nano-particles into a low vapor–pressure liquid

2. **Chemical reduction**: Metallic nano-particles are prepared in various solvents by reducing metal salts into nanofluids. E.g. cuprous oxide nanofluids were prepared by chemical reduction of copper acetate by glucose in the presence of sodium lauryl sulfate (SLS)

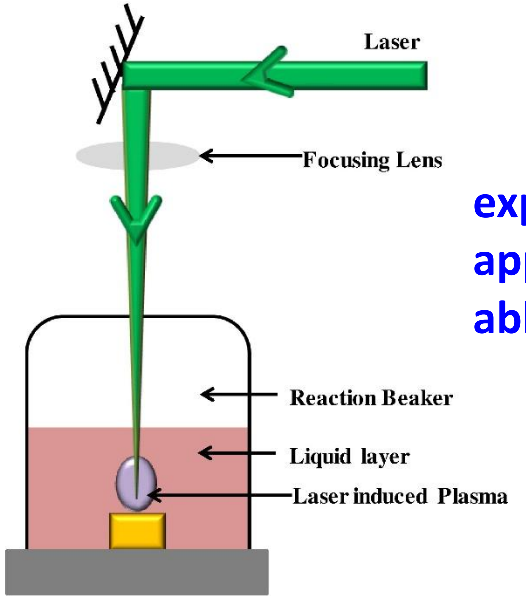
3. **Submerged arc nanoparticle synthesis system**: A stable CuO nanofluid is prepared by submerged arc nanoparticle synthesis system (SANSS), where a pure copper rod is submerged in a dielectric liquid in vacuum chamber.



submerged arc nanoparticle synthesis system.

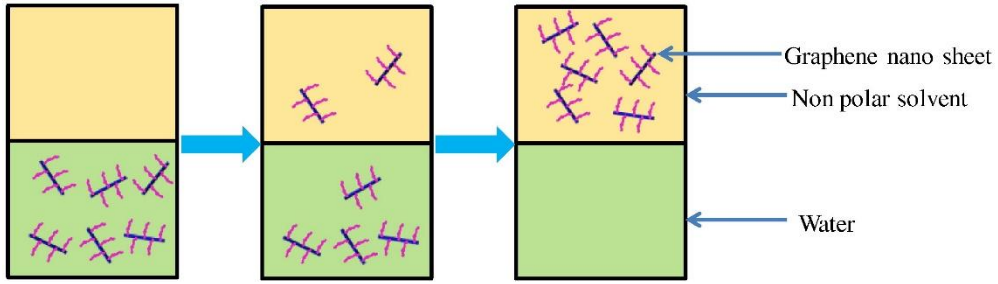
The one step processes used to prepare nanofluids:

4. **Laser ablation**: another direct evaporation & dispersion technique; solid metals such as Cu, Ag, Au which are submerged in the base fluid (e.g. water and lubrication oils) are ablated - produces stable nanofluids without addition of dispersant



experimental apparatus for laser ablation.

5. **Microwave irradiation**: approach adopted for nanofluids synthesis is based on microwave irradiation
6. **Polyol process**: In the polyol process, a metal precursor is dissolved in a liquid polyol (usually ethylene glycol) to reduce the metallic precursor, followed by nucleation and growth
7. **Phase-transfer method**: the reactant migrates from one phase into another phase where the reaction occurs. It has advantage of overcoming the problems associated with the insolubility of precursor materials in base fluids

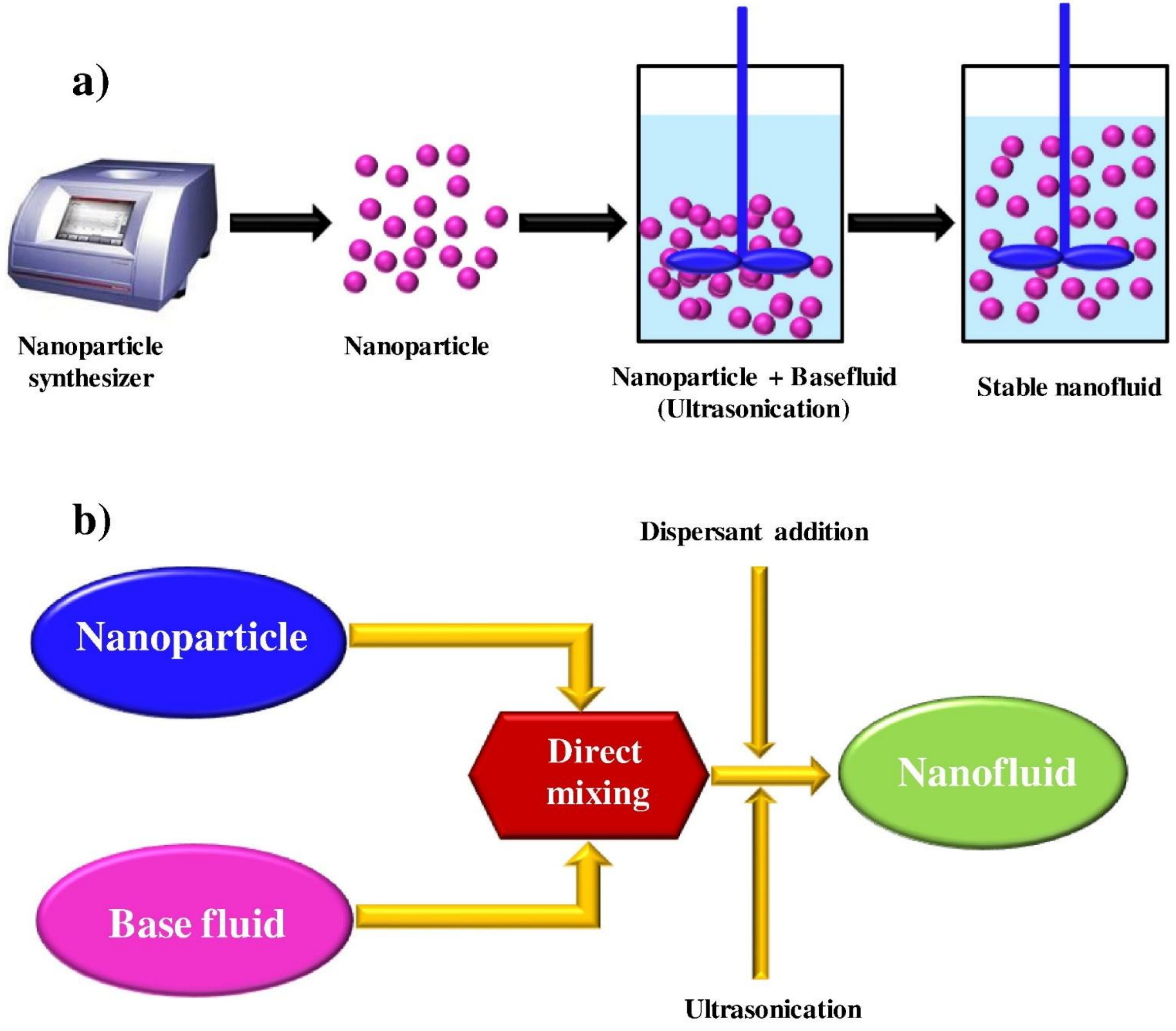


the phase transfer process for preparation of graphene oxide nanosheets

Two step preparation process of nanofluids:

(a) Nanoparticles prepared by microwave synthesizer & particles are dispersed in base fluid by mechanical stirrer.

(b) Direct mixing of nanoparticles followed by addition of dispersant & ultrasonication.



Questions/ Discussion

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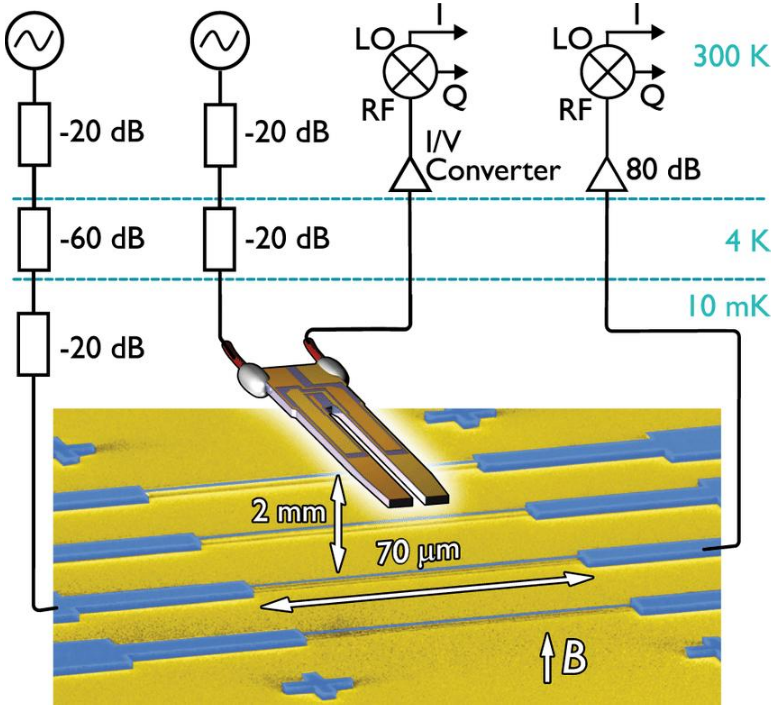
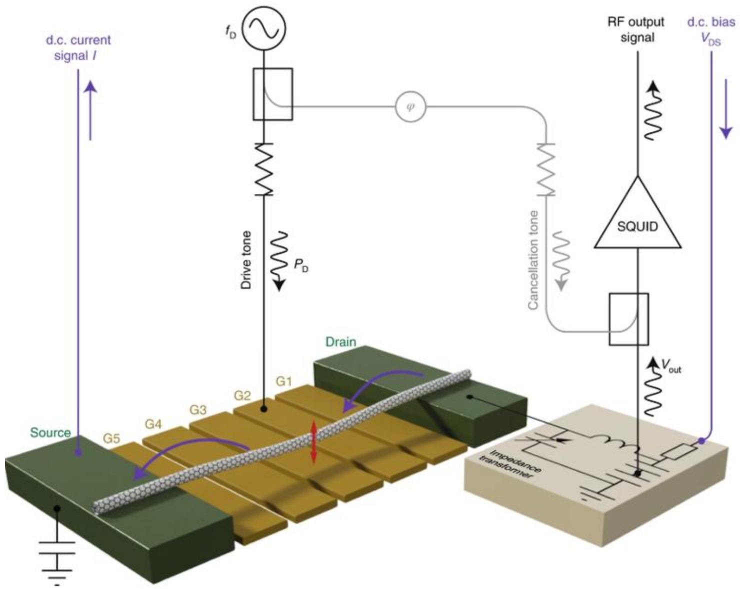
Nanomechanical oscillators

Nanomechanical oscillators and resonators are tiny devices that vibrate at specific frequencies.

- They're like microscopic tuning forks, responding to **forces** and **changes** in their environment.
- These devices are **crucial** for sensing, measuring, and processing information at the nanoscale.



Microscopic tuning fork



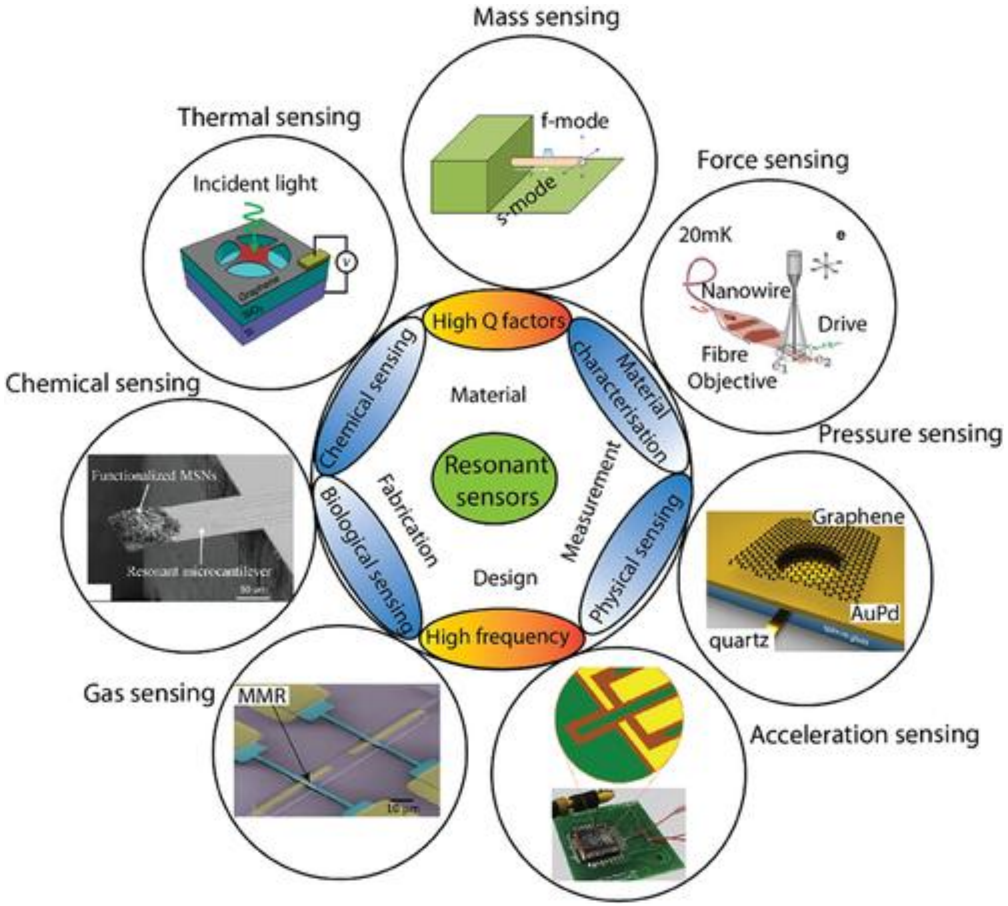
A nanomechanical oscillator

Nanomechanical oscillators

- Nanomechanical oscillators have been employed as precision sensors in a diverse range of physical measurements.
- These tiny yet powerful mechanical sensors reached the single-phonon regime, and they demonstrate operations near ground states repeatedly.

Nanomechanical oscillators have been used as:

- highly sensitive mass detectors of individual cells and adsorbed chemicals.
- to study mechanical loss mechanisms with dimensions such that surface-to-volume ratios become important.
- their damping effects have been investigated where the amplitude of motion of the oscillator is **comparable** to the mean free path of the gas molecules.



Nanomechanical oscillators

- The oscillators are made from
  - **Polymers** like methyl methacrylate nanofibers,
  - **single crystalline silicon**,
  - **polycrystalline** silicon,
  - **silicon nitride**, and
  - **nanocrystalline diamond films**, etc.
- They are fabricated using either
  - electron beam lithography or
  - high-resolution projection lithography.

Nanoscale Heat Transfer

- Heat transfer at nanoscale is of importance for many nanotechnology applications
- *There are typically two types of problems*
  - One is the management of heat generated in nanoscale devices to maintain the **functionality** and **reliability** of these devices.
  - The other is to utilize nanostructures to manipulate the heat flow and energy conversion

Examples:

- Thermal management of nanodevices are the heating issues in integrated circuits and in semiconductor lasers
- The manipulation of heat flow and energy conversion include
  - nanostructures for thermoelectric energy Conversion,
  - thermo-photovoltaic power generation

- Heat transfer at nanoscale may **differ significantly** from that in macro- and microscales.
- With **device or structure characteristic length scales** becoming **comparable** to the
  - Mean free path and
  - Wavelength of heat carriers (electrons, photons, phonons, and molecules),
- Classical laws are no longer valid and new approaches must be taken to predict heat transfer at nanoscale

Some distinct characteristics of heat transfer at macroscale are:

1. Thermal conductivity is a material property which depends on the detailed microstructure of the material but is independent of the size of the material.
2. The maximum thermal radiation heat transfer between any objects is limited by the blackbody radiation.
3. In convection, the fluid in contact with the solid assumes the same velocity & temperature, as the solid at the point of contact, the so-called **no-slip condition**

For heat transfer in nanostructures, some of these characteristics for macroscale heat transfer disappear.

- Heat conduction can be ballistic and similar to thermal radiation
- Thermal conductivity is no longer a material property;
- The slip of molecules at fluid–solid interface must be considered

Questions/ Discussion