

Ultrasonic Electrospinning with a Focused Ultrasonic Nozzle

Needle-free production of sub-micron polymer fibers using a MicroSpray 60 kHz focused ultrasonic nozzle, as demonstrated in US Patent 12,421,630 B2 (Virginia Commonwealth University)

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Abstract

Electrospinning produces fine and ultrafine polymer fibers but is limited industrially by low throughput: a conventional spinneret emits one fiber jet. US Patent 12,421,630 B2 (D. Chen, Virginia Commonwealth University, granted September 23, 2025) describes a needle-free method in which ultrasonic vibration forms a standing wave on the polymer meniscus at a nozzle exit surface, and an applied electric field draws fibers simultaneously from multiple wave peaks. The working example used a commercially available MicroSpray 60 kHz focused ultrasonic spray nozzle mounted tip-up, grounded, with 15-20 kV on a collector 3.5-4 in. away. Polyacrylonitrile (PAN) in DMF produced mean fiber diameters from 0.33 μm (8 wt%) to 1.26 μm (14 wt%) at 60 $\mu\text{L}/\text{min}$, with fiber size controllable through polymer concentration and feed rate. This paper summarizes the method, the role of the ultrasonic nozzle, and configuration guidance for laboratories adopting the approach.

1. Background

Electrospinning is widely used to make fibers for filtration and separation, drug-delivery patches, biological scaffolds, and materials research. Its throughput bottleneck comes from the single-capillary spinneret. Multi-needle heads increase output but require uniform solution distribution to every needle and are difficult to manufacture consistently as needle count grows. Needle-free spinnerets instead draw fibers from the crests of a rippled liquid surface. Bubble electrospinning, one such approach, requires injecting gas bubbles that rise slowly to the surface under gravity.

Ultrasonic spray nozzles have long been used to atomize liquids into fine droplets. Prior art (for example US 4,659,014, US 4,655,393, US 2008/0265055, US 2014/0011318) treated ultrasonic energy strictly as a spraying tool. Earlier reactive-electrospinning work (US 8,066,932) even kept ultrasonic power low and the transducer far from the capillary exit to avoid disturbing the jet. The VCU patent inverts that assumption.

2. The ultrasonic electrospinning method

The nozzle exit surface is vibrated by an ultrasonic generator so the polymer solution on it forms a standing wave. With a voltage differential between the exit surface and a target, each wave peak becomes a jetting site and multiple fibers are drawn at once. Additional mechanisms reported in the patent:

- At higher acoustic power, cavitation generates gas bubbles in the solution. Vibration drives them quickly to the meniscus, where they create further irregular crests and jetting sites, without gas injection.
- Ultrasonic heating lowers solution viscosity and surface tension, so jetting begins at lower voltage. Lower voltage reduces energy use, component stress, and the risk of reaching the arcing threshold of the surrounding gas.
- A feedback loop (camera plus controller) can monitor the standing wave and adjust vibration frequency to stabilize jetting positions.

The patent's independent claim covers conducting liquid to the exit surface of an electrospinning nozzle, vibrating that surface with acoustic energy so the liquid forms a standing wave, supplying a voltage differential to a target, and controlling both to induce fiber jetting from the wave peaks. Frequencies from 18 kHz to several MHz are contemplated.

3. Experimental setup with the MicroSpray nozzle

Parameter	Value
Nozzle	MicroSpray focused ultrasonic spray nozzle, 60 kHz, with air shroud
Orientation	Exit pointing upward; convex meniscus forms on the tip
Electrical	Nozzle grounded; DC high voltage 15-20 kV on collector (Bertan 203-30R supply)
Distance	3.5-4 in. (90-100 mm) nozzle to collector
Collector	Metal disk with 5 in. central hole hung from an insulated plate; adjustable along plastic rods
Shroud air	Dry sheath air to dry fibers in flight; nozzle tip protruded beyond the shroud exit to minimize focusing
Feed	Harvard Apparatus programmable syringe pump, 60 and 120 $\mu\text{L}/\text{min}$
Polymer	PAN (MW 150,000) in DMF (99.8%), 6, 8, 10, 12, 14 wt%
Characterization	Hitachi SU-70 FE-SEM; ImageJ size distributions; viscometry of solutions

Mounting the nozzle exit upward is central to the method: gravity lets a convex meniscus form on the tip, and cavitation bubbles rise naturally toward the liquid-gas interface.

4. Results

PAN concentration	Feed rate	Mean fiber diameter
8 wt%	60 $\mu\text{L}/\text{min}$ (18.5 kV)	0.326 μm , SD 0.082 μm
10 wt%	60 $\mu\text{L}/\text{min}$	about 0.64 μm
14 wt%	60 $\mu\text{L}/\text{min}$	1.255 μm , SD 0.273 μm

Fiber diameter increased with polymer concentration at fixed feed rate, attributed to the roughly proportional rise in solution viscosity. At each concentration, raising the feed rate from 60 to 120 $\mu\text{L}/\text{min}$ increased fiber size. Multiple fibers were emitted from the rippled meniscus in every run, and the process produced fibers in both sub-micron and super-micron ranges.

5. Why a focused ultrasonic nozzle suits electrospinning

1. **The atomizing tip is the exit surface.** MicroSpray nozzles deliver liquid through a large internal channel onto a tip driven by a Langevin-type transducer. The liquid rests directly on the vibrating surface, which is exactly what the method requires.
2. **Same physics, different endpoint.** In spray mode, acoustic perturbations in the liquid film drive capillary wave growth, ligament formation, and droplet breakup. In electrospinning mode, the electric field pulls fibers from the wave crests before breakup, so the capillary wave pattern defines the jetting sites. Capillary wavelength scales as $(8\pi\sigma / (\rho f^2))^{1/3}$; higher frequency shortens the wavelength and increases the number of crests per unit area.
3. **Shroud air repurposed.** The air-shroud focusing feature was used as a dry sheath to solidify fibers in flight.
4. **Non-clogging feed.** Viscous polymer solutions pass freely through the nozzle's feed channel.
5. **Standalone integration.** Nozzle, generator, syringe pump, and a laboratory HV supply form a complete rig; no proprietary platform is needed.

6. Applications

The patent emphasizes filtration media, where finer fibers reduce pressure drop at constant particle capture efficiency, and thin nanofiber layers on industrial cartridges improve reverse-pulse cleaning. Separation membranes, wound dressings and drug-delivery mats, biological scaffolds, and non-polymer nanofibers are also cited. Multiple jets per nozzle and the option of nozzle arrays give a scaling path with commercial hardware.

7. Configuration guidance for adopters

- **Frequency.** The example used 60 kHz. Higher frequencies (e.g., 120 kHz) shorten the capillary wavelength and may increase jetting-site density; lower frequencies suit higher-viscosity or higher-flow feeds.
- **Mounting.** Tip-up orientation with a convex meniscus. Provide a stable mechanical mount isolated from the HV field.
- **Electrical safety.** Ground the nozzle and generator; apply HV to the collector. If HV must be applied at the nozzle, an isolated nozzle assembly is required, as the patent describes.
- **Sheath air.** Use the shroud for dry air delivery; extend the tip beyond the shroud exit if focusing is not wanted.
- **Feed.** Syringe pump at tens to hundreds of $\mu\text{L}/\text{min}$; match to polymer viscosity.

- **Process control.** Fiber diameter tunes with polymer concentration and feed rate; a camera on the meniscus enables closed-loop frequency adjustment.

8. References

1. D. Chen, "Ultrasonic electrospinning for the production of fine and ultrafine fibers," US Patent 12,421,630 B2, assigned to Virginia Commonwealth University; filed Feb. 14, 2023 (Appl. No. 18/168,961); granted Sept. 23, 2025. <https://patents.google.com/patent/US12421630B2/en>
2. US 2024/0191400 A1, pre-grant publication, June 13, 2024.
3. Prior art cited in the patent: US 4,659,014; US 4,655,393; US 2008/0265055 A1; US 2014/0011318 A1; US 8,066,932 B2.

Data in this paper are summarized from the published patent. MicroSpray Brands was not involved in the VCU research.