Laser 'Lightning rods' channel electricity through thin air

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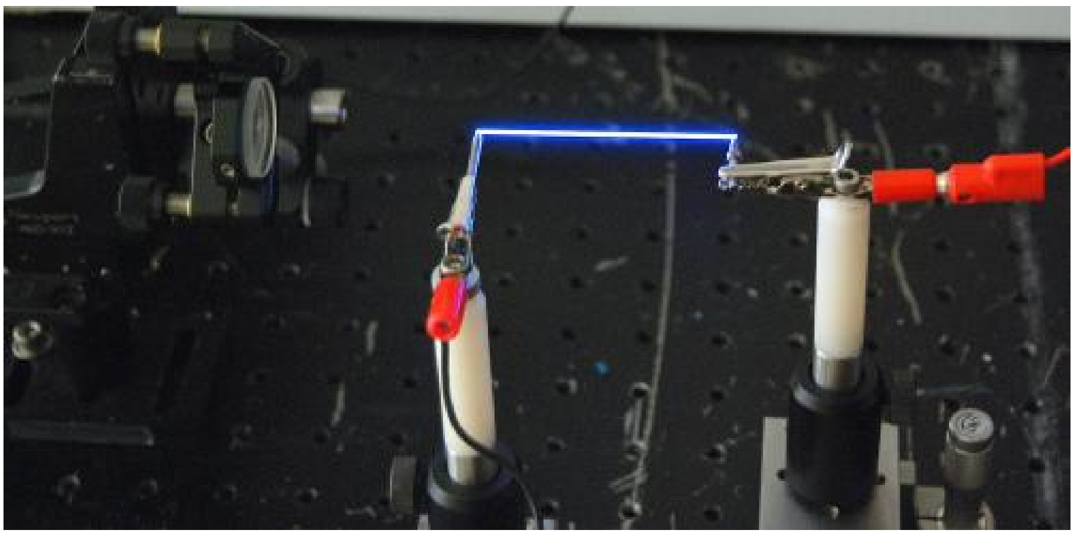

Miniature lightning: The team used a femtosecond laser to create a thin column of plasma – a special charged state of matter – in the air between two electrodes. Credit: Pavel Polynkin

By zapping the air with a pair of powerful laser bursts, researchers at the University of Arizona have created highly focused pathways that can channel electricity through the atmosphere.

The new technique can potentially direct an electrical discharge up to 10 meters (33 feet) away or more, shattering previous distance records for transmitting electricity through air. It also raises the intriguing possibility of one day channeling lightning with laser power.

Described in a paper published in The Optical Society's new open-access journal Optica, the current system may have near-term, lifesaving applications in areas such as the remote detonation of land mines, the researchers speculate. The laser system could easily pinpoint an active land mine and then carry an electric pulse strong enough to safely discharge harmful explosives from afar.

The team used a femtosecond laser to create a thin column of plasma – a special charged state of matter – in the air between two electrodes. A femtosecond is one millionth of a billionth of a second. Femtosecond lasers emit pulses that last only a few tens of femtoseconds.

Before this narrow plasma channel has a chance to dissipate, an almost simultaneous burst from a nanosecond laser – lasting a million times longer than a femtosecond pulse – retraces the same path, giving it an extra jolt of heat and the staying power necessary to transmit electricity.

The team was led by Pavel Polynkin, associate research professor of optical sciences at the University of Arizona College of Optical Sciences.

"By creating a combined one-two punch of laser light, we could first open a doorway through the air and then wedge it open just long enough to control and direct electricity through the atmosphere," said Polynkin, the paper's corresponding author. "This incredibly rapid double burst of energy is what was needed to overcome some otherwise daunting challenges."

In this image, the thin beam of a filament laser is barely visible against the tabletop surface. Credit: Pavel Polynkin

Using Lasers to Channel Lightning

The idea of using lasers to channel electricity through the air, which is not normally conductive, was first proposed in the 1970s and further explored through the 1990s. The research was based on the idea that by superheating a very narrow column of air, it would be possible to create a straight path along which an electric charge could flow.

These early attempts used nanosecond lasers, which were the most practical lasers at the time due to their intense power and very short duration. The highly focused laser beams superheated a narrow line of air molecules, stripping off their outer electrons and producing a filament of charged plasma. The higher-than-normal concentration of free electrons in the plasma overcame the atmosphere's natural insulator properties, making it much more conductive. Under laboratory conditions, researchers were, at the time, able to produce a filament of approximately 1 meter in length.

With the advent of more advanced femtosecond lasers, however, Polynkin and his team felt they could utilize the advantages brought about by both femtosecond and nanosecond lasers and achieve much better results through combining the two types of lasers in a single powerful beam.

Earlier this year, a joint team from the UA and the University of Central Florida, which included the authors of the new Optica paper, presented a new approach involving a high-intensity laser beam inside a "dress beam" refueling the primary beam and sustaining it over much greater distances than were previously possible.

"In both experiments, we used two synchronized laser pulses to produce plasma in air," Polynkin said. "But the nature of the second pulse is different in the two cases. Instead of the dress beam, which only lasted femtoseconds, we now use a much more energetic pulse of longer duration – several nanoseconds – that we call heater pulse."

Extending the Reach and Duration With More Lasers

The current breakthrough was achieved by sending a femtosecond laser light pulse as the "igniter" and a nanosecond pulse as a "heater" along the same path, and by understanding how the atmosphere behaves when it was subjected to these extremely energetic light pulses. The researchers recognized that it wasn't the actual plasma created by the lasers that made the atmosphere more conductive; it was the subsequent superheating that lowered the density of the filament of air. Without some additional input of energy, however, this zone of lower density quickly collapsed. To improve both distance and duration, a second energy source was needed to rapidly reheat the air, stabilizing the filament just long enough to carry an electrical current.

"Since the first femtosecond laser already blazed the trail, we were able to harness a second nanosecond laser, following the same path, to rapidly pump more heat into the system," said Polynkin. "This channel lasted considerably longer, so we had the potential to extend the previous distance record by more than tenfold."

The filaments the researchers created significantly lowered what is known as the electrical breakdown point, the voltage that is needed to overcome the insulating effect of the atmosphere. Lightning, because of its incredibly high voltage, routinely overcomes the air's natural resistance, although in highly random and unpredictable ways.

Based on their initial results, the researchers believe that other forms of heater beams, such as microwaves or long-wavelength lasers, could further increase the distances they were able to achieve, though other issues would need to be addressed before applications like channeling lightning could be achieved.

As a next step, the researchers are planning on using a microwave beam in place of the nanosecond laser to more efficiently heat the channel and perhaps achieve better results.

More information: "Channeling the electrical breakdown of air by optically heated plasma filaments." Maik Scheller, Norman Born, Weibo Cheng, and Pavel Polynkin. *Optica,* Vol. 1, Issue 2, pp. 125-128 (2014). dx.doi.org/10.1364/OPTICA.1.000125

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