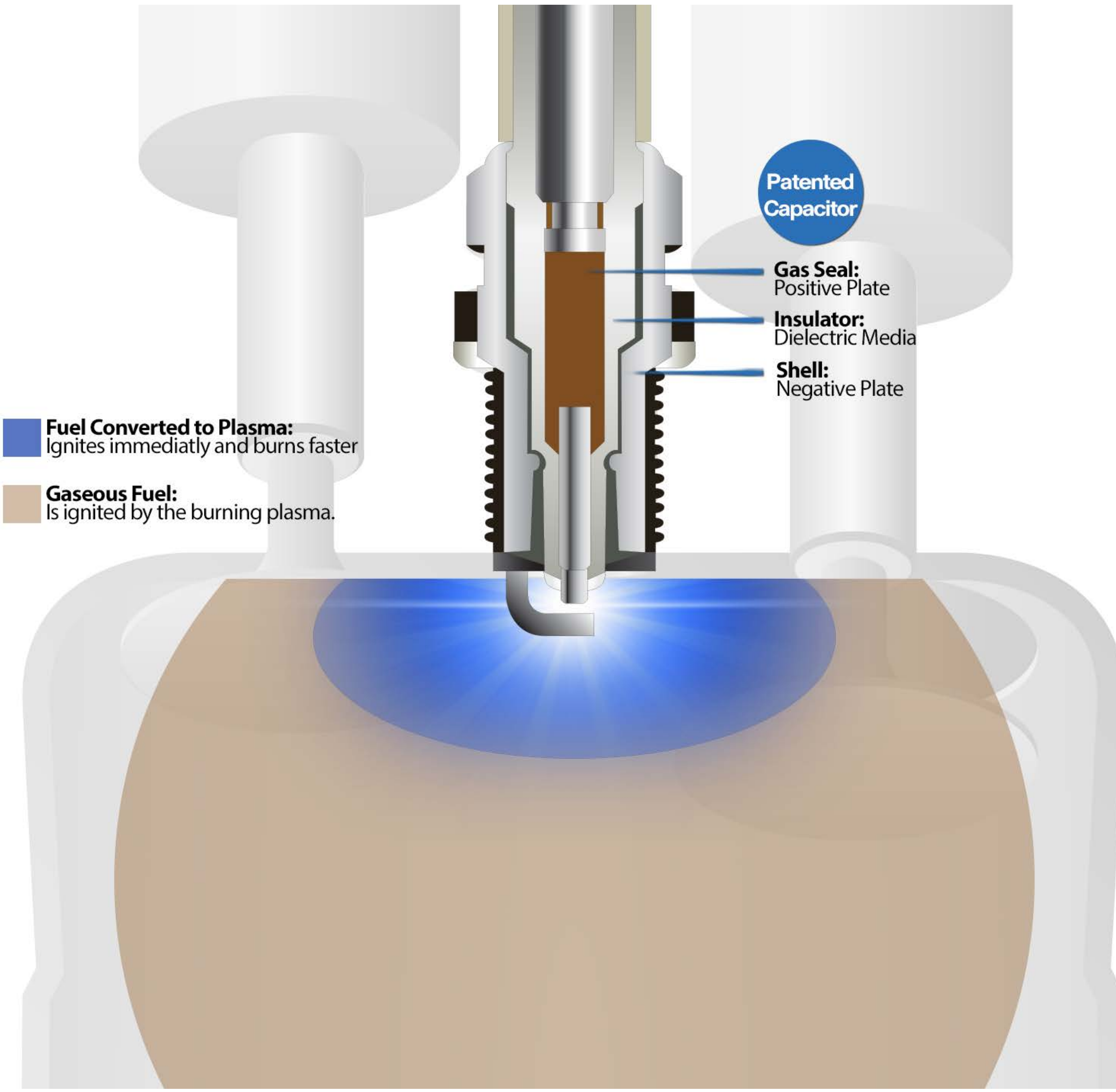
Pulstar Spark Plugs: How They Work

Bigger Spark | More Power | Longer Life

Summary

Pulstar® Spark Plugs burn the air-fuel mixture more efficiently by converting a portion from a gaseous state to a highly excited plasma state. Pulstar® Spark Plugs store energy in a patented internal capacitor prior to spark creation. When breakdown voltage occurs and a spark is formed, the energy stored in Pulstar's capacitor is released in a 5MW nanosecond pulse. This intense electrical pulse projects into the cylinder and interacts with the surrounding gaseous air-fuel mixture, converting it to plasma. The plasma saturated portion of the air-fuel mixture ignites immediately and burns at an accelerated rate; rapidly igniting the remaining gaseous air-fuel mixture by exposing it to a large surface area of flame. This innovative process burns the air-fuel mixture more efficiently and completely, extracting more energy from the fuel.



The Four Stroke Engine

The vast majority of engines use a four-stroke design, where each piston completes four separate strokes to comprise a single thermodynamic cycle. These four strokes are: intake, compression, power, and exhaust.

1. **Intake:** Beginning at Top Dead Center (TDC), the piston descends within the cylinder. This movement sucks a mixture of fuel and air into the cylinder through the intake port via the intake valve.
2. **Compression:** Both intake and exhaust valves close and the piston returns to the top of the cylinder compressing the air-fuel mixture into the combustion chamber resident in the cylinder head.
3. **Power:** Slightly before Top Dead Center (BTDC) the compressed air–fuel mixture is ignited by a spark plug. The piston is forced back down as the fuel mixture is combusted, creating pressure.
4. **Exhaust:** The piston returns to TDC while the exhaust valve is open, ejecting the burned and unburned fuel-air mixture through the exhaust valve(s). **Emissions are composed of the burned and unburned fuel-air mixture.**

The Power

Power is created by the expanding gasses forcing the piston down at just the right time during the power stroke. If the spark occurs to early, the piston is either still on its way up during the compression stroke or the crank is not far enough past TDC to take advantage of the pressure from the expanding gasses – wasting energy. If force is applied too late, the expanding volume of combustion gasses does not provide enough pressure to generate power. In newer cars, a computer determines how much power is required and adjusts the amount of ignition timing and fuel delivered to **minimize fuel usage (MPG)** and ensure enough pressure is created by the burned air-fuel mixture to apply the appropriate force to the piston at just the right time – **maximizing horsepower and torque.**

How can horsepower, torque, and MPG be improved while reducing emissions? By burning more of the air-fuel mixture during the time allotted by the power stroke.

The Spark Plug

A spark plug creates a spark with the electric current and voltage from the ignition coil to ignite the compressed air-fuel mixture. In most engines, the flow of the air-fuel mixture is targeted to intersect with the space between the center electrode and ground electrode where the spark forms – known as the spark gap. By intersecting the fuel mixture with the spark gap, engine makers attempt to ensure the fuel mixture is ignited quickly by the concurrent spark.

The Pulstar Difference

Pulstar spark plugs use plasma technology to enhance engine performance. Energy stored in Pulstar® Spark Plug's integrated capacitor is released in an intense nanosecond pulse, converting a portion of the gaseous fuel mixture into a highly excited plasma that conditions the fuel mixture to ignite immediately and burn efficiently. Quicker throttle response, increased horsepower and torque, and improved fuel efficiency are achieved by a more consistent and complete burn of the air-fuel mixture during the power stroke, creating more force on the piston to apply more torque to the crankshaft and power to the wheels.

Pulstar® with PlasmaCore Plugs have four components that allow them to burn more of the air-fuel mixture:

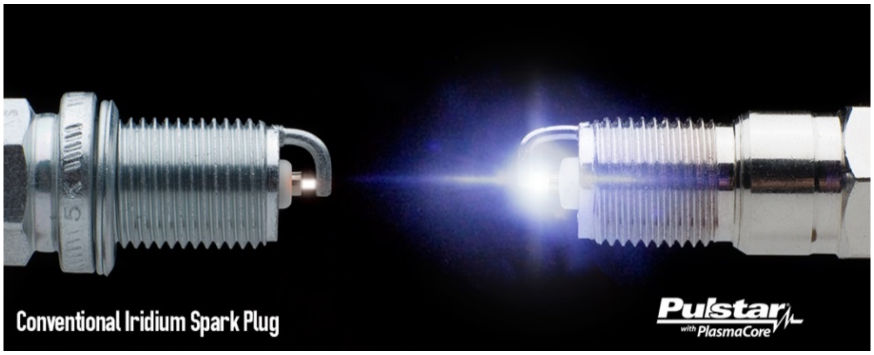
Pulstar® Core Capacitor
Pulstar® Plasma-forming Pulse
Pulstar® Plasma Assited Combustion
Pulstar® Electrode

The Pulstar Capacitor

A typical capacitor has three parts: a positive plate, a negative plate, and a dielectric media. The positive plate attracts the energy while the negative plate provides it access to ground. The dielectric media prevents the energy from crossing between the two plates, forcing the energy to collect and be "stored" on the positive plate.

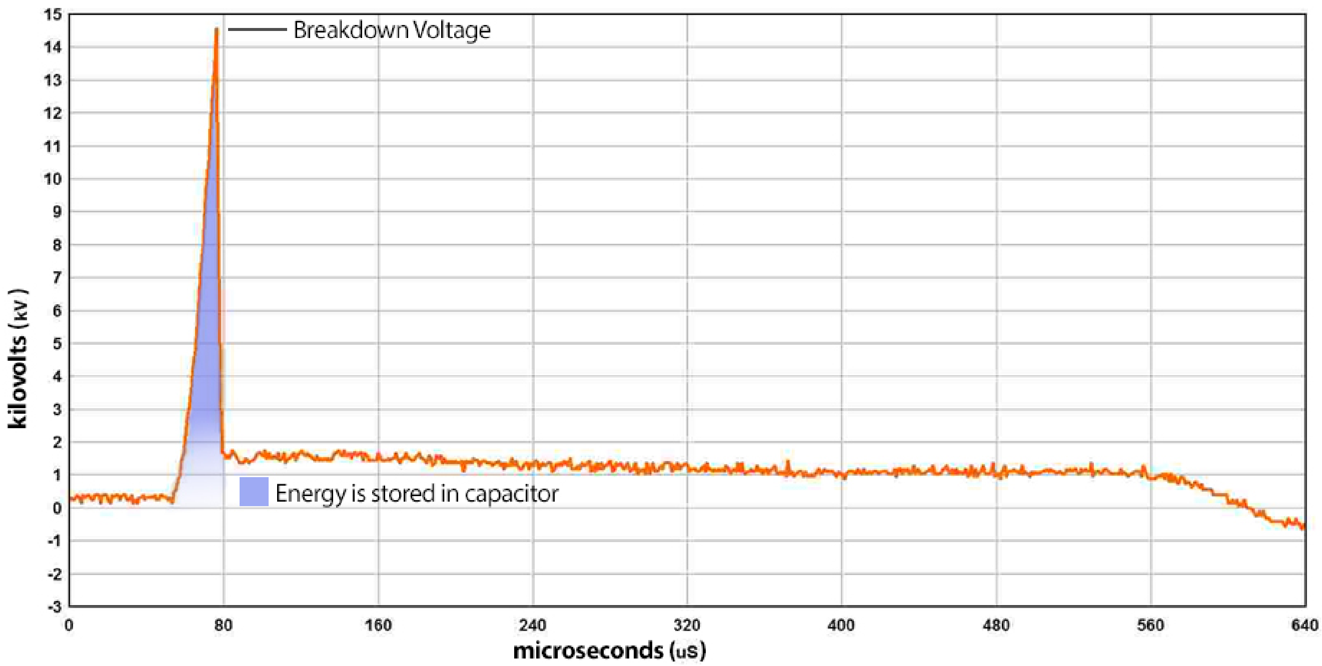
Pulstar® Spark Plugs use the copper gas seal as a positive plate, slowly accumulating energy delivered by the ignition coil. All spark plugs are electrically grounded by screwing into the engine's cylinder head with its threaded metal shell. In Pulstar® Spark Plugs, the threaded metal shell acts as the negative plate – giving access to ground. Pulstar's insulator acts as the dielectric media that prevents energy from crossing from the positive plate to the negative.

The Pulstar Pulse



Pulsed power is the relatively slow accumulation of energy followed by its rapid release, resulting in the delivery of a larger amount of instantaneous power over a shorter period of time. Energy stored within electrostatic fields (capacitors) is released over a very short interval (a process that is called energy compression), delivering a huge amount of peak power. For example, if one joule of energy is stored within a capacitor and then evenly released over one second, the peak power delivered would only be 1 watt. However, if all of the stored energy were released within one microsecond, the peak power would be one megawatt, a million times greater. Examples where pulsed power technology is commonly used include radar, particle accelerators, ultra-strong magnetic fields, fusion research, electromagnetic pulses, and high power pulsed lasers.

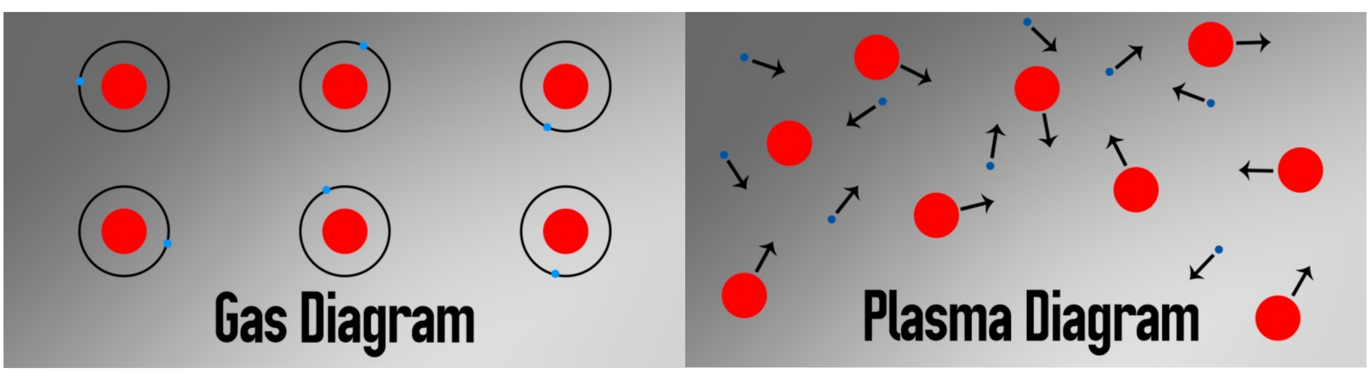
To form a spark, a vehicles ignition coil will slowly (relative to the process) inductively increase the voltage delivered to the spark plug until enough voltage is being delivered to allow electricity to bridge the air-fuel mixture between the center electrode and ground strap of the spark plug. This is known as achieving breakdown voltage. Pulstar Spark Plugs use the copper gas seal, ceramic insulator, and metal shell to form a capacitor that stores energy delivered by the vehicles ignition coil prior to achieving breakdown voltage. When a spark is formed by energy flowing between the two electrodes, the energy stored in the capacitor is also released. This release of energy creates a pulse equal to 5,000,000 watts and takes approximately three nanoseconds to complete. The pulse is so intense that it converts a portion of the gaseous air-fuel mixture into a highly excited plasma that conditions the fuel mixture to ignite immediately and burn efficiently.



High-speed video video taken has captured the Pulstar® plasma-forming pulse and its accelerated flame-front (combustion). Captured by AVL, the world's largest independent company for the development of powertrain systems with internal combustion engines, this video shows the pulse, followed by the plasma pre-sensitized fuel mixture burning at twice the rate of the conventional spark plug.

Pulstar Plasma Assisted Combustion

Liquid, solid and gas are the three well known states of matter; by subjecting gas to a large amount of energy the fourth state, plasma, is formed.



For instance, this diagram shows gas atoms with a positive core and orbiting negative electrons. To form plasma, these gas atoms are subjected to a large amount of energy and broken apart to form a collection of positively and negatively charged highly reactive particles. Plasma consists of positively charged ions with most or all of their detached electrons moving freely about in a very active manner; these electrons react with other atoms.

Pulstar stores energy accumulated over a relatively long period of time in its internal capacitor and releases it entirely in less than three nanoseconds. This massive dump of energy happens so quickly that the pulse it forms is equal to 5 megawatts. This 5 MW pulse interacts with the gaseous air-fuel mixture, breaking its molecules apart. Pulstar breaks down natural elements like H_2 and O_2 into their atomic state of H and O where they are most volatile. Thus, the portion of the air-fuel mixture affected by the pulse has been turned into plasma.

Plasma created by the high-intensity pulse of energy results in three major benefits in fuel combustion: instant ignition, a quicker and more complete burn.

Instant Ignition

Temperature Increase. The high-intensity pulse creates a flash of heat that helps the fuel charge reach the required light-off temperature to ignite the air-fuel mixture. The flash point for gasoline is about 600°F and 1,100°F for natural gas. The heat provided by the plasma, gives the air-fuel mixture a head start to achieving the temperature required to ignite.

Volatile Air-fuel Mixture. The high-intensity pulse breaks down air-fuel components like H_2 and O_2 into their atomic state of H and O where they are most volatile. These highly excited elements along with radicals react to the ensuing spark by igniting instantly.

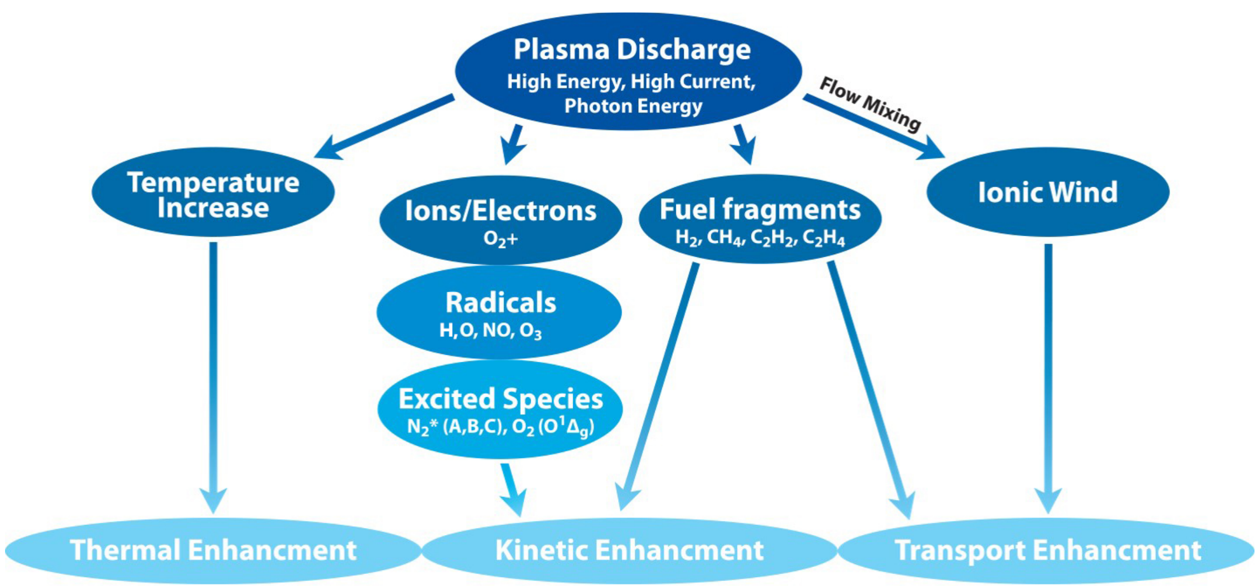
Quicker Burn

Fuel Fragments. The high-intensity pulse breaks apart the long hydrocarbon chains found in the nearby air-fuel mixture into shorter chains that react quickly. This area of the air-fuel mixture burns faster.

Complete Burn

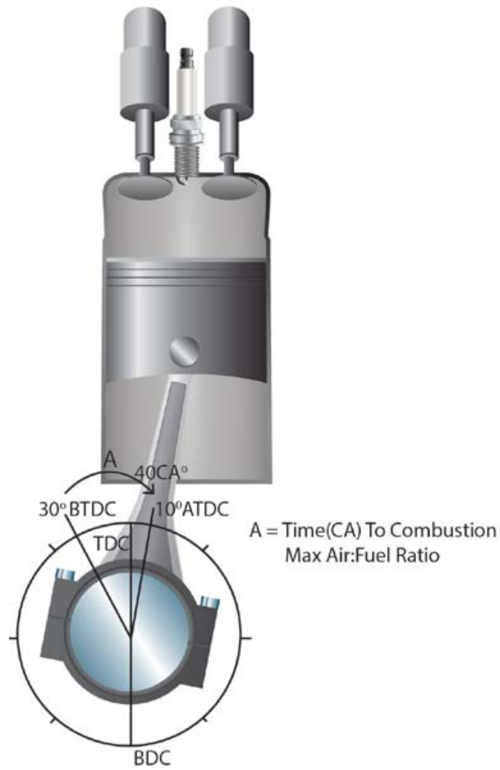
Fuel Fragments. The portion of the fuel that contains shortened hydrocarbon chains burns faster, and creates a larger surface area to ignite the rest of the gaseous air-fuel mixture. This allows the air-fuel mixture to burn more completely during the power stroke.

Ionic Wind. The high-intensity pulse knocks off electrons from the air-fuel mixture molecules. These ions are thrown out of orbit and knock off additional ions from neighboring molecules, creating a cascading effect. This process helps expand the formation of plasma beyond the high-intensity pulse's immediate vicinity. As previously mentioned, this plasma field burns at an accelerated rate.



SUN Wentng and JU Yiguang, (Princeton) J. Plasma Fusion Research Vol 89, No 4 (2013)

The Pulstar Electrode



In order to extract the most power out of a fuel charge, every engine must start to burn the fuel a few degrees of crank angle before the piston reaches top dead center (TDC) during the compression stroke to produce the most combustion pressure during the power stroke. If the fuel is burned too late, the momentum of the pressure created by the combusting fuel-mixture is wasted because the piston is already on its way down in the exhaust stroke. If the fuel is burned too soon, the pressure created by the combusting fuel-mixture is wasted because it is trying to force the piston down before it has cleared top dead center. However, if the fuel is burned at just the right time the piston is forced down with the maximum amount of combustion pressure to create the best horsepower, torque, and fuel economy.

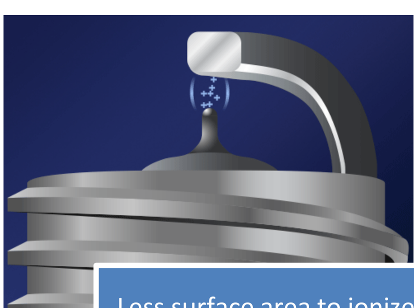
Two things can stop the piston from being forced down at just the right time:

1. The spark doesn't form in time.
2. The fuel doesn't ignite, or it takes too long to ignite.

The first possibility is a problem that has plagued spark plug makers since the inception of the spark plug. When the piston reaches the optimum point, the ignition coil begins to send electrical current to the spark plug to form a spark. The electrical current attempts to get to ground but cannot because it must first cross the air between the center electrode and ground electrode of the spark plug. Before the energy can cross the spark gap, it must build a bridge of ions in the air between the two electrodes. The ignition coil slowly (relative to the process) increases the voltage until a strong enough electrical field is formed to ionize the spark gap – this is known as spark jump voltage or breakdown voltage. Once the ions become concentrated enough, the energy finally flows across the spark gap, forming the spark.

More surface area to ionize

For many years, spark plug makers used a large diameter electrode in an attempt to extend the life of their spark plugs. Unfortunately, larger electrodes create a larger surface area where ions can form. Spark creation timing is less consistent because the time it takes to form a condensed amount of ions in one area is random.



Less surface area to ionize

In an effort to increase spark creation consistency, spark plug manufactures moved to a fine center-wire plug. The smaller diameter surface area allows ions to form in a compressed area, ensuring a more consistent spark formation. As previously mentioned consistent spark creation ensures that the fuel-mixture is ignited at the optimal time; resulting in a smoother idle, quicker throttle response and improved engine performance. According to DENSO®, their fine-wire electrode plug "redefines performance driving with the worlds smallest iridium alloy electrode diameter of 0.4mm" by "[enabling] a high concentration of electrical field which requires lower jump spark voltage. This improves ignition performance, eliminates misfiring and translates into high performance driving. The lower required voltage and high ignitability from the iridium electrode also guarantees smoother idling, improved acceleration and high response driving."

Pulstar with PlasmaCore plugs are able to take advantage of a larger electrode because our plug's capacitor converts a portion of the air-fuel mixture in to plasma and produces a spark channel 10 times larger than conventional plugs. These features allow Pulstar pulse plugs to ignite the fuel mixture instantaneously upon spark creation, and burn it more quickly. Pulstar plugs ensure precise combustion no matter the size of the electrode because we can burn more of the fuel consistently, even if it takes longer to ionize the spark gap. Additionally, our large nickel-chromium superalloy electrode extends the life of the plug by slowing electrode wear to preserve your spark gap.

This animated image demonstrates how the fine wire electrode ionizes the spark gap quicker than the large diameter electrode by compressing the electrical field. More consistent spark creation results because the ions are forced to form a conductive bridge between the positive and negative electrodes in a condensed area. The fine-wire flame kernel is initiated at a more consistent time during each ignition cycle but is rather small in volume. The wide electrode takes longer to create a spark because the ions take longer to form the conductive bridge because of the less concentrated field. The Pulstar with PlasmaCore plug also creates the spark at various times; however the initial flame front is significantly larger and burns the fuel more quickly upon spark creation which results in more consistent and complete ignition. This is made possible by the plasma field formed by the Pulstar PlasmaCore plug. Again, click here to see actual footage of Pulstar's burn compared to a leading brands premium fine-wire iridium plug as captured by AVL, the world's largest independent company for the development of powertrain systems with internal combustion engines.