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Plasma Dental Brush

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"Painless" Plasma Brush Is Becoming Reality In Dentistry, MU Engineers Say

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COLUMBIA, Mo. – University of Missouri engineers and their research collaborators at Nanova, Inc. are one step closer to a painless way to replace fillings. After favorable results in the lab, human clinical trials are underway on the "plasma brush."

In less than 30 seconds, the plasma brush uses chemical reactions to disinfect and clean out cavities for fillings. In addition to the bacteria-killing properties, the "cool flame" from the plasma brush forms a better bond for cavity fillings. The chemical reactions involved with the plasma brush actually change the surface of the tooth, which allows for a strong and robust bonding with the filling material.

"There have been no side effects reported during the lab trials, and we expect the human trials to help us improve the prototype," said Qingsong Yu, associate professor of mechanical and aerospace engineering of MU, and Meng Chen, chief scientist from Nanova, Inc., which holds a co-patent for the plasma brush with MU.

"200 million tooth restorations cost Americans an estimated $50 billion a year, and it is estimated that replacement fillings comprise 75 percent of a dentist's work. The plasma brush would help reduce those costs," said Hao Li, associate professor of mechanical and aerospace engineering in the MU College of Engineering. "In addition, a tooth can only support two or three restorations before it must be pulled. Our studies indicate that fillings are 60 percent stronger with the plasma brush, which would increase the filling lifespan. This would be a big benefit to the patient, as well as dentists and insurance companies."

The research and development team also includes Yong Wang from the School of Dentistry at University of Missouri-Kansas City and Liang Hong from the School of Dentistry at University of Tennessee-Memphis. The project has been funded by the National Science Foundation and the National Institutes of Health. Li, along with Yu and Chen, have formed Nanova, Inc., with Chen leading the plasma brush device development through the NIH Small Business Innovation Research (SBIR) program.

Human clinical trials are expected to begin in early 2012 at the University of Tennessee-Memphis. The researchers believe the human clinical trials will provide the data that allow Nanova to find investors and take the next steps in placing the product on the market. If the studies go well and the FDA clears the use, the researchers' timeline indicates the plasma brush could be available to dentists as early as the end of 2013.

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Atmospheric Non-Thermal Gas Plasma Method for Dental Surface Treatment

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Abstract -- The provision of dental restorations can be improved by generating a cold atmospheric plasma inside the mouth of the patient and then applying that cold atmospheric plasma onto a dental restoration site. The dental restoration site can be composed of either or both of dentin and enamel. Further, the provision of dental restorations can also be improved by introducing a dental adhesive onto a dental restoration site and treating it with a cold atmospheric plasma.

BACKGROUND OF THE INVENTION

[0003] The present disclosure relates to dental cavity repair and treatment. More specifically, the present disclosure relates to a surface treatment method for targeted dentin and dental materials using a cold atmospheric discharge plasma technique to improve the clinical performance and durability of dental restorations.

[0004] Dental fillings are commonly used to treat dental cavities resulting from caries. Caries is the formal name for the disease that causes tooth decay or the formation of what are commonly referred to as cavities. Caries causes tooth decay resulting in decayed matter forming in the tooth, the location of the decayed matter often being referred to as a cavity. As many know, the tooth has an enamel outer layer that covers a thicker layer of dentin. The enamel protects the dentin, and in turn, the dentin protects the pulp of the tooth that contains flesh, including sensitive nerves. Failure of the enamel and the dentin to protect the pulp, whether from accident or caries, is a toothache.

[0005] To treat caries, the decayed matter in the cavities needs be removed and the cavities are disinfected and filled. The removal of the decayed matter is usually performed by a dental drill. The materials for the filling are most commonly dental amalgam or composite material. Conventionally, an adhesive is used to firmly connect the tooth to the filling. Adhesives are also used for crowns and caps. A generic term that encompasses fillings, crowns, caps and other structures installed in a tooth to remedy a defect in the tooth is restorations.

[0006] Also, one restoration is being replaced with another restoration can be performed. Such replacement is sometimes, but not always, accompanied by the presence of additional decay that needs removal. The prior restoration will usually be removed in the course of this work, sometimes by drilling, but also by other means in situations such as where a crown or a cap is being removed.

[0007] The tooth may be formed to have a recess in the tooth, as is common for dental fillings. But the tooth may also be formed into a post or the like, such as when caps are installed.

[0008] Where the surfaces of the tooth, adhesive and filling meet each other are called interfaces. For a properly installed filling there is an interface between tooth and adhesive and an interface between adhesive and filling. Fillings have high failure rates at these interfaces and often need to be replaced later.

[0009] Failure is particularly prominent in composite dental materials. Composite restoration has become the preferred form of restorative material because of patients' aesthetic requirements and the aversion of patients and dentists to the potential health risk of mercury release from dental amalgams. But composite restorations do not last as long as dental amalgams. Some of the reasons for premature failures of composite restoration include dental composite shrinkage, inadequate bonding of the adhesive to dentin, and formation of a second cavity at the edges of or under the restoration.

[0010] Recent studies show that many recorded filling failures occur at the tooth-adhesive interface. These failures are caused by the failure of the adhesive bonding attaching the filling material/composite to the dentin of the tooth. One study has reported that about 70% of composite restoration failures at the back of the mouth occur at the dentin-composite interface. The failure of the adhesive to maintain bonding results in the separation of the composite restoration from dentin. The resulting gaps lead to staining at the margins of the restoration, sensitivity, and recurrent caries, which cause a significant portion of composite restoration removal and replacements.

[0011] Studies also show that adhesion between enamel and composite is generally adequate for clinical applications, while adhesive/dentin bonds are the weak link and the interfacial bond strength in the composite restoration deteriorates significantly over time. The disruption of the bonded interface can develop as a consequence of long-term thermal and mechanical stresses, or during the restorative procedure itself, due to stresses generated by composite polymer shrinkage.

[0012] Foods and saliva are perpetually in the mouth, and further, bacteria are always present. These can cause problems for the adhesive working to maintain bonding at the restoration-dentin interface. Unsuccessful dentin bonding also means that there are sites at the tooth restoration interface that are vulnerable to hydrolytic breakdown and susceptible to attack by bacterial enzymes. Clinical performance needs to improve when polymer-based dental composites are to be considered viable alternative to dental amalgam. The desired improvements include enhancing the bonding strength at the adhesive/dentin interface to resist polymerization shrinkage and to make it impervious to oral fluids.

[0013] Currently, the preparation and disinfection of dental cavities (dentin surfaces) prior to filling relies on mechanical drilling or laser techniques to remove dead (synonymous with necrotic), infected, and non-remineralizable tissue. Both methods are often destructive and can be painful for patients due to mechanical stimulation (vibration) and heating of the dental nerve. To ensure sufficient disinfection, an excess healthy tissue must be removed using the current methods, since dentine contains many small channels in which bacteria can hide. Moreover, the disinfection process itself, with the current methods, can also lead to fracture of dentin.

[0014] Several studies and techniques for the preparation/disinfection process have been attempted to improve the interface bonding strength, but with only limited success. For example, U.S. Pat. No. 6,172,130 describes surface treatment of dental prosthesis composed of polymers containing hydrogen atoms using gas phase plasma in a vacuumed reactor vessel operated at 13.56 MHz. The plasma treated polymers are characterized by the hydrogen atoms on the surface of the polymer being partially replaced by fluorine atoms. The type of modified polymers is claimed to be able to improve the retention of the prosthesis and/or limit the development of dental plaque. However, this plasma process, due to its requirement of reduced-pressure environment, is not suitable for surface treatment of the dentin of living subjects in dental clinics.

[0015] Therefore, there is a need to develop a new and improved preparation/disinfection method employing the cold atmospheric plasma technology, which can chemically activate dentin surface to implement chemical bonding and enhance adhesion strength at dentin-composite interfaces, and consequently to increase the longevity of dental restorations, as well as to be more cost-effective and less painful to patients.

SUMMARY OF INVENTION

[0016] A method of surface treatment for providing a dental restoration can include generating a cold atmospheric plasma inside the mouth of the patient and then applying that cold atmospheric plasma onto a dental restoration site. The dental restoration site can be composed of either or both of dentin and enamel. Also, the surface of dental adhesive present after introducing a dental adhesive onto a tooth can also constitute a dental restoration site that can be beneficially treated with a cold atmospheric plasma.

[0017] The dental restoration can also have a surface of dental composite layers. The temperature of the cold atmospheric plasma can range from about 10[deg.] C. to about 50[deg.] C. with temperatures of about 35[deg.] C. to about 39[deg.] C. being preferred for patient comfort in most applications. The gas that is excited into the cold atmospheric plasma can be helium, argon, nitrogen, oxygen, nitrous oxide, ammonia, carbon dioxide, water vapor, air, gaseous hydrocarbons, gaseous silicon-carbons, gaseous fluorocarbons or mixtures thereof.

[0018] Also, the atmospheric plasma can be applied to the restoration site for a period of about 10 seconds to a period of about 2 minutes. In addition to measuring exposure by a fixed time interval, the method contemplates the atmospheric plasma being applied to the restoration site for a period of time that enhances the strength of the adhesive-site interface.

[0019] The cold atmospheric plasma appears to be most beneficial to the periphery of a dental restoration site.

[0020] This disclosure also contemplates a method of installing a dental restoration on a tooth inside of a patient's mouth where material is removed from a tooth to expose a surface comprising dentin or enamel. The exposed surface is then treated with a dentally acceptable acid to clean it, and then the acid is removed to stop the acid-tooth reaction. Then cold atmospheric plasma is generated inside the mouth of the patient and applied onto the exposed surface. Then a dental adhesive is applied to the surface. Optionally the cold atmospheric plasma can be applied to the adhesive-coated surface. Then a dental restoration can be installed on the adhesive coated surface.

BRIEF DESCRIPTION OF DRAWINGS

[0021] FIG. 1 is a schematic of the apparatus to generate a cold atmospheric plasma.

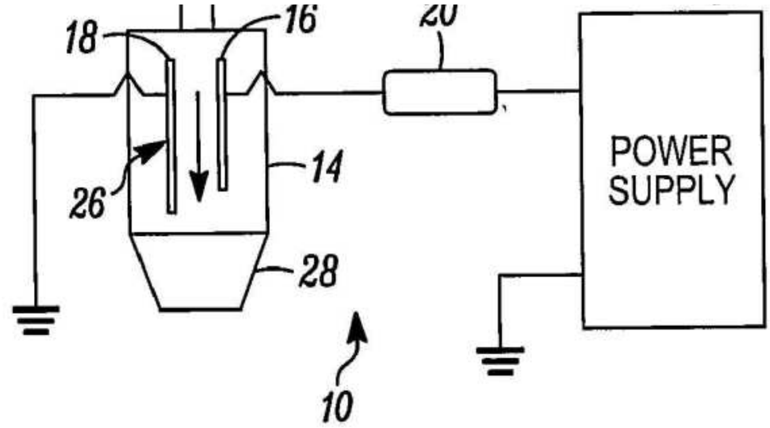

FIG. 1

[0022] FIGS. 2(a) and 2(b) are drawings of the cold atmospheric plasma source suitable for dental applications, according to one embodiment of the invention.

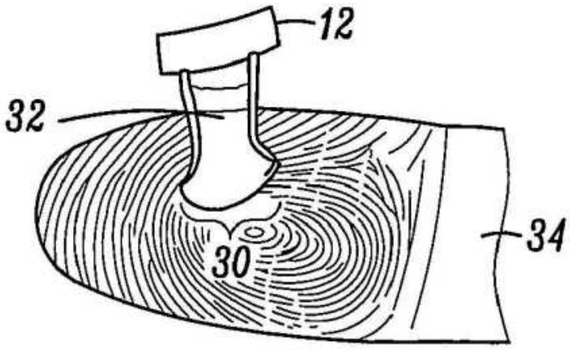

FIG. 2A

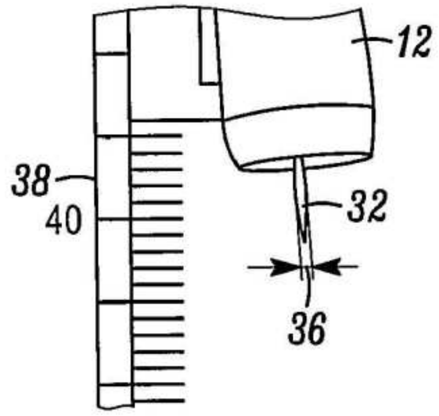

FIG. 2B

[0023] FIG. 3 shows the various plasma temperatures at different plasma operating conditions, including power input and argon flow rate.

[0024] FIG. 4 shows the Fourier Transform Infrared (FTIR) spectrum change of dentin at surface before and after plasma treatment.

[0025] FIG. 5 shows the plasma treatment effects on cell survival curves of Streptococcus mutans, which is the most common bacterium causing dental cavity.

[0026] FIG. 6 illustrates the bonding strength improvement for dental composite restoration induced by plasma treatment of dentin/composite interfaces.

[0027] FIGS. 7(a)-(d) is a drawing of SEMs taken of fracture surfaces where the fracture occurs at different interfaces depending on plasma treatment time.

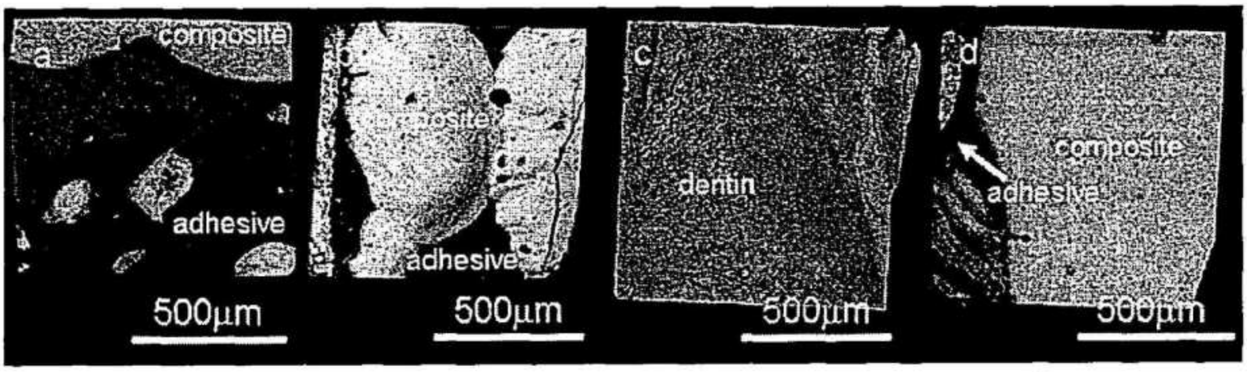

FIG. 7

DETAILED DESCRIPTION OF THE INVENTION

[0028] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety.

[0029] The present disclosure reveals a new and improved surface treatment method using cold atmospheric plasma brush technology that can be used in dental restoration for dental cavity treatment, preparation, and surface modification of related dental fillings. The disclosed treatments can be safely used inside the mouth of a patient without causing more pain than is common to standard dental work. The surface treatment method can be employed in any surface to activate chemical bonding effect, particularly the surfaces of a dental filling site in a dental restoration, such as dentin surface, dental enamel surface, dental-adhesive surface, and dental-filling surface. The method for surface treatment at a dental restoration site during a dental restoration can include generating cold atmospheric plasma at an appropriate temperature and directing the plasma jet onto a desired surface at the dental restoration site for duration sufficient to change the surface characteristics in ways that facilitate bonding of the treated site with adhesives.

[0030] Cold plasmas, or low-temperature gas plasmas, are partially ionized gases that contain highly reactive particles including electronically excited atoms, molecules, ionic and free radical species, while the gas phase remains near room temperature. Depending on the plasma chemistry or gas composition, these highly reactive plasma species clean, and etch surface materials, bond to various substrates, or combine to form a nanoscale thin layer of plasma coating, and consequently alter the surface characteristics. These non-equilibrium plasmas combine exceptional chemical activity with relatively mild, non-destructive characteristics due to the room-temperature gas phase.

[0031] The cold atmospheric plasma can comprise plasma gases of helium, argon, nitrogen, oxygen, nitrous oxide, ammonia, carbon dioxide, water vapor, air, gaseous hydrocarbons, gaseous fluorocarbons, gaseous silicon-carbons, and mixtures of them. Desirably, the temperature of the plasma can range from about 20 to about 50[deg.] C., with about 37+-2[deg.] C. as preferred. The surface of the desired dental filling site can be the surface of a dentin, the surface of dental enamel, the surface of a dental adhesive, or the surface of a dental filling. The term, "adhesive" or "dental adhesive" refers to a composition used on a dental structure (e.g., a tooth) to adhere a restoration material to it. Non-limiting examples of such products are listed in Table 1.

[0000]
TABLE 1

Company Name	Bonding Products
3M/ESPE	Prompt L-Pop, Prompt SE, Scotchbond SE, Scotchbond Multipurpose Plus, Scotchbond Multipurpose, Easy Bond SE, Single Bond Plus
ALL DENTAL PRODUCTS	ComposiRepair
BISCO	Elitebond, All-Bond 2, All-Bond 3, All-Bond SE, One Step, One Step Plus, Tyrian SPE
CENTRIX	Multibond, Adhere
COLTENE WHALEDENT	One Coat Bond, One Coat 7.0, One Coat SE, Coltene ART Bond
COOLEY & COOLEY	Snapbond
COSMEDENT	Powerbond, Complete
DE TREY/DENTSPLY	PRIME & BOND NT, Xeno III, Xeno IV, XP Bond, ProBond
DENMAT	Tenure Bond, Tenure S, Tenure Uni-Bond, Tenure A&B,

Tenure Quick
DISCUS DENTAL Cabrio
GC AMERICA Fuji Bond LC, Unifil Bond LC
HENRY SCHEIN Dentin Bonding Agent, Natural Elegance Prime Bond, Sun Schein Bond
HERAEUS KULZER Gluma Solid Bond, Denthesive II, Gluma Comfort Bond, Gluma One Bond, Gluma Gold Bond, i Bond, i Bond SE
IVOCLAR/VIVADENT ExciTE, Heliobond, Syntac Sprint, Syntac Single Component, Syntac 3, AdheSE
J. MORITA One up Bond F, M-Bond
KERR XR-Bond, Optibond, Optibond FL, Optibond Solo, Optibond Solo Plus, Self Etching, Optibond All in One
KURARAY Clearfil liner bond 2, Clearfil liner bond 2V, Clearfil DC Bond, Clearfil SE bond, Clearfil Photobond, S3 Bond, New Bond
L.D. CAULK/ Prime & Bond NR, Probond, Xeno III, Xeno IV, XP Bond
DENTSPLY
PARKELL Touch & Bond, Easy Bond, C&B Metabond, Totalbond, Brush & Bond, Etch Free
PENTRON CLINICAL Bond 1, Nano Bond, Bond 1 SF Solvent Free SE, Bond It,
TECHNOLOGIES Bond 1 C&B
PREMIER Integrabond, Bond Boost SE
PULPDENT Dentastic Uno, Dentastic Uno Duo, Dentastic
SHOFU Imperva Bond, Beautibond, Fl Bond
TOKUYAMA Mac-bond II, Bond Force
ULTRADENT Permaquik, Permagen, PQ1
VOCO Solobond M, Admira Bond

[0032] Cold plasma surface treatments, when employed to modify the surface of the dentine, can increase adhesive penetration into collagen fibrils leading to a more effective hybrid layer and increasing chemical bonding between the collage fibrils and the dental adhesive. The plasma can also act as a primer for the collagen fibers. Low temperature plasmas in particular, when modifying polymers for adhesion, can be tailored to reduce the negative effects seen with other preparatory methods such as surface roughening, wet chemical treatments, or exposure to flames.

[0033] Dentin is largely a matrix of hydroxyapatite having fibrils of collagen distributed within the hydroxyapatite. While not wishing to be bound by theory, it is believed that when utilized correctly and efficiently cold plasma is a gentle method used to increase the wettability of the topmost layer of polymeric surfaces, such as collagen fibrils, without negatively affecting the underlying material. Plasma can also uniquely tailor the surface of polymeric materials by addition of reactive gases in small quantities, which permits the plasma to easily modify and enhance the surface characteristics of various types of adhesives. Additionally, cold atmospheric plasma is a good candidate to sterilize the surface of surgical instrumentation to prevent bacterial infection, which in turn decreases the chance of the composite failing because of the formation of secondary caries.

[0034] The inventive surface treatment method for a dental filling site includes the steps of 1) generating cold atmospheric plasma at a pre-determined temperature, and 2) directing the plasma onto a desired surface at the dental filling site for duration sufficient to change the surface characteristics.

[0035] FIG. 1, is a schematic illustration of a typical dental plasma brush and related power supply. The plasma brush device 10 contains a plasma brush generator 12 that includes a walled, narrow gas chamber 14 and two electrodes 16 & 18, which are located inside the gas chamber 14. The hot wire electrode 16 is connected to an optional ballasted resistor 20 that can be used to restrain the discharge current coming from the external power source 22. The grounded electrode 18 is connected to ground.

[0036] A working gas 24 can be introduced into the gas chamber 14. When electrical power is applied through the electrodes 16 & 18, the gas in the gas chamber 14 is excited. A glow discharge plasma 26 of the gas flowing through the plasma generator will be formed. The discharge plasma 26 will exit through a nozzle 28, which can be disposable for control of hygiene.

[0037] The electrodes can be powered by an external power source 22. The atmospheric pressure plasma can be generated and maintained by electric power input from a direct current or alternating current, audio or radio frequency, or pulsed power supplies. The working gas 24 can be helium, argon, nitrogen, oxygen, nitrous oxide, ammonia, carbon dioxide, water vapor, air, gaseous hydrocarbons, gaseous fluorocarbons, gaseous silicon-carbons, and mixtures thereof. Argon or air is preferred in certain dental applications, such as enhancement of bonding strength in dental restoration, or disinfection of dental bacteria. The duration of each surface treatment varies depending upon the particular application, but commonly run less than 60 seconds.

[0038] A nozzle 28 is used to direct the flow of the discharge plasma out of the gas chamber 14. The nozzle 28 can be in any shape. For example, the exit from the nozzle 28 can be round, oval or square, or other desirable shape. Additionally, it is desirable for the shape of the gas chamber 14 to complement the shape of the nozzle 28.

[0039] One operable shape is a nozzle 28 that is relatively narrow in a first direction generally perpendicular to the flow of gas and relatively wide in a second direction transverse to the first direction but still generally perpendicular to the flow of gas. Such a nozzle 28 forms plasma with a brush-like shape at the exit of the chamber. Operatively, when the nozzle 28 forms a brush of plasma, the gas chamber 14 is dimensioned slit-like to complement the nozzle 28.

[0040] While the plasma brush would be operable without a ballasted resistor 20, glow-to-arc transitions can be prevented by a ballasted resistor 20 and working gas 24 appropriate to the narrow slit chamber design. The brush-like shaped plasma extends beyond the exit of the chamber, and possesses there active features of low-pressure or non-equilibrium plasmas. The resultant low-pressure or non-equilibrium gasses can be used to treat surfaces of dentin, enamel, adhesive, or dental composite layer for dental composite filling.

[0041] Further information on the plasma brush are incorporated by reference as if fully set forth herein from Y. X. Duan, C. Huang, Q. S. Yu, 2005, "Low-temperature direct current glow discharges at atmospheric pressure", IEEE Transactions on Plasma Science, 33, p. 328-329.

[0042] The plasma can be directed to the surface of dentin, enamel, dental adhesives, or dental fillings. FIG. 2(a) is a side view facing a broad aspect 30 of the plasma brush 32. The width of the plasma brush is desirably in the range of 1 to 10 mm. The diagram shows the plasma to be safe to apply to a human finger 34, which can be readily done. FIG. 2(b) shows a side view facing the narrow aspect 36 of the plasma "brush." The narrow aspect 36 of the plasma brush 32 has a thickness of about 1-5 mm, and is desirable in the range of 1 to 3 mm. A ruler 38 is also shown indicating a length 40 for the plasma brush 32 of about 5 mm, and is desirable in the range of 5 to 12 mm.

[0043] When employing the atmospheric plasma brush, the size and temperature of the plasma can be easily controlled by varying the plasma input power mainly through adjusting the electrical current to the electrodes and gas flow rate passing the plasma chamber. The desired temperature of the plasma ranges from about 20 to about 50[deg.] C. A plasma temperature of about 37+-2[deg.] C. is preferred for work in humans. It should be noted that the temperature can be adjusted to suit the comfort of a particular patient or other species of animal.

[0044] FIG. 3 is a graph showing various plasma temperatures under different generating conditions. Line 42 denotes the thermocouple temperature (Y-axis) as a function of power source wattage at a constant flow of argon gas at 2000 standard cubic centimeters per minute (sccm). Line 44 shows the same at a flow rate of 3000 sccm, line 46 at 4000 sccm, and line 48 at 5000 sccm. Thermocouple, IR imaging, and thermometers, when used in correlation, can be used to provide a reasonable range of the plasma temperatures.

[0045] The plasma temperature profile of the described atmospheric plasma brush was established by taking thermal IR images. In comparison with the plasma temperatures measured using a thermocouple, it was noted that an average of 5[deg.] C. higher temperature was recorded using the IR imaging method. The nerve system of human teeth is very sensitive to temperature differences. The results of the thermal imaging study indicate that the plasma temperature of the plasma brush can be well controlled to be close to human body temperature.

[0046] The duration of treatment can vary from 5 seconds to 10 minutes. The preferred treatment time will be in the range of 10 seconds to 2 minutes and the most preferred range will be in the range of 10 seconds to 60 seconds.

[0047] In a particular application, dentin surfaces were treated by argon plasma brush at room temperature for 0, 30, 100, and 300 sec. Adper Single Bond Plus dental adhesive (3M ESPE) and Filtek Z250 composite (3M ESPE) were applied and light cured as directed.

[0048] FIG. 4 shows the Fourier Transform Infrared (FTIR) spectrum change of dentin surface before plasma treatment 50 and after plasma treatment 52. The FTIR spectrum change after plasma treatment shows that there is a significant chemical change on the dentin surface. One change is the increase of carbonyl groups present at the surface, shown in area 54, which can contribute, in part, to the enhancement of the bonding strength at dentin-composite interfaces. While not wishing to be bound by theory, the formation of more carbonyl groups on the collagen fibers can increase hydrogen bonding between adhesive and fiber. These additional functional groups also can permit the collagen fibers to disaggregate after rewetting because of the electrical repulsive forces, which can significantly increase the surface area of the collagen fibers and in turn the bonding strength of the collagen fibers to adhesives.

[0049] This can be understood in view of the composition of representative collagens and adhesives. Type I collagen is one type of collagen present in dentin. Type I collagen is generally about [1/3] glycine and [1/6] proline or hydroxyproline. Lysine, hydroxylysine, and histidine are generally involved in cross-linking type I collagen molecules into fibrils. ADPER SINGLE BOND PLUS is a representative dental adhesive. ADPER SINGLE BOND PLUS comprises BisGMA, dimethacrylates, HEMA, VITREBOND polyalkenoic acid copolymer, water, ethanol, and silica nanoparticles. All of these can have hydrogen bonding with the recited components of Type I collagen.

[0050] Dentin collagen has 3 times the hydroxylysine as skin collagen. When treated with HEMA and glutaraldehyde only 18% of the lysine and 15% of the hydroxylysine are cross-linked. Steric hindrance prevents more than 80% of the free amino acids from interacting with the adhesive. As a result, opportunities for hydrogen bonding are severely reduced in a collagen fiber as compared to the separate parts of a collagen molecule.

[0051] While not wishing to be bound by theory, the plasma is thought to disaggregate the triple helix. The result of the disaggregation can be that the amino acids that were held in the interior of the triple helix are exposed by breaking up the triple helix. Not only does this result in more amino acids being exposed, it increases the surface area exposed for adhesion by taking surface area that was on the inside of a fiber, and making that surface area available for adhesion.

[0052] The techniques of the present disclosure result in an increase in the ultimate tensile strength for the dentin-composite bond induced by plasma treatment of dentin-composite interfaces at the margins of the interfaces. The increase of carbonyl groups on plasma treated dentin surfaces shown in the FTIR implies the treatment effect is due to the reactive species in the plasma rather than the heat produced from the plasma brush. Both heat treated and plasma treated surfaces show an amide II shift. In other words, plasma treatment did induce chemical structural changes on the collagen fibrils, which determines the final interfacial bonding strength of dental composite restorations.

[0053] Furthermore, the plasma treatment at the dental filling site provides additional disinfection effects besides improving bonding strength. FIG. 5 shows the plasma treatment effects on cell survival curves of Streptococcus mutans, the most common bacterium causing dental cavity. The Y-axis of FIG. 5 is the Y-axis of colony-forming unit (CFU), a measure of viable bacterial numbers, and the X-axis is the treatment time with argon at a flow rate of 2000 sccm. Line 56 represents the results at 5 W of power, line 58 at 10 W of power and line 60 at 15 W of power. The results shown in FIG. 5 demonstrate that plasma treatment can also effectively and rapidly disinfect bacteria in the cavity.

EXAMPLE 1

[0054] An atmospheric cold plasma brush (ACPB), a non-thermal gas plasma source, was used to treat and prepare dentin surfaces for dental adhesive and dental composite application. Extracted unerupted human third molars were used for this investigation. The occlusal one-third of the crown was sectioned by means of a water-cooled low speed diamond saw (Buehler, Lake Bluff, Ill.). The exposed dentin surfaces were polished with 600 grit SiC sand papers under water and then etched using 36% phosphoric acid. Dentin surfaces were Ar plasma treated for 0, 30, 60, and 300 sec. A flow rate of 2500 sccm and a power of 5 watts were chosen. The results of these treatments are shown in FIG. 6. Oxygen additions at various flow rates were also tested. Adper Single Bond Plus dental adhesive (3M ESPE) and Filtek Z250 composite (3M ESPE) were applied and light cured as directed. Dentin/composite bars (8-10 mm*1 mm*1 mm) were cut from the prepared teeth for tensile testing and interface characterization. The chemical structural changes of the plasma treated dentins were characterized by FTIR. Fracture surfaces were characterized by SEM (Philips XL30 ESEM-FEG).

[0055] When plasma treatment was not used, the strength of a dentin-adhesive interface was 36.8+-10.5 Mpa. But 30 seconds of plasma treatment on the dentin surface increased the tensile strength of the dentin/adhesive interface of peripheral dentin to 60.4+-15.7 Mpa. These findings were confirmed with SEM. The notion of peripheral dentin is understood in the art. One definition is given by viewing the tooth from above. If the dentin is above pulp, it is central and the remaining area is peripheral. It can also be understood as being the most peripheral 1 to 2 mm or so of the tooth. The SEM observations show increased areas of composite on the fracture surface when compared to the untreated control samples. It was found that numerous plasma treated samples failed in locations other than the dentin/adhesive interface, while most of the control samples failed at the interface. The periphery is an area that in a particular planned or installed restoration is most exposed to the contents of the mouth, including, but not limited to, saliva, bacteria and food.

EXAMPLE 2

[0056] SEM images shown in FIGS. 7(a)-(d) have been taken of the fracture surfaces that can be generated using methods of this disclosure. FIGS. 7(a)-(d) represent back scattered SEM images of the fracture surfaces of the test specimens prepared from: (a) the untreated controls (0 sec), (b) 30 sec, (c) 100 sec, and (d) 300 sec plasma treated dentin. The resulting SEM images showed that more composite remained on dentin surfaces plasma treated for 30 seconds when compared with controls. This illustrates that rather than the fissure occurring in the adhesive-dentin interface, the break occurs in the composite instead, showing that the adhesion of the interface is stronger than the internal strength of the composite.

[0057] Fracture modes were determined and recorded. Table 2 presents micro tensile test data and fracture location of the specimens prepared from plasma treated dentin and the untreated controls (0 sec treatment)

[0000]
TABLE 2

Treatment Time	0 s	30 s
Bonding Strength		
Average Stress (MPa)	38.80	60.38
Standard Deviation (MPa)	8.66	15.66
Average Modulus (GPa)	642.49	963.45
Standard Deviation (GPa)	64.48	98.05
Fracture Location (%)		
Interface	84.62%	50.00%
Composite	15.38%	50.00%
Dentin	0.00%	0.00%
Zapit	0.00%	0.00%

[0058] More specimens cohesively failed in the composite for plasma treated specimens compared to controls, except for the specimens prepared from 300 s plasma treated dentin specimens. Control specimens had adhesive or mixed failures more frequently than the plasma treated specimens. SEM examination of the fractured cross sections showed that large amounts of composite/adhesive were observed on 30 s plasma treated dentin surfaces, which implies the dentin-adhesive interface is stronger than the bulk composite. These trends were also observed with the test specimens that gave higher tensile strength. Plasma treated specimens cohesively failed within the composite more frequently than the control specimens which also implies a stronger interface.

[0059] While the invention has been described in connection with specific embodiments thereof, it will be understood that the inventive methodology is capable of further modifications. This patent application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as can be applied to the essential features herein before set forth and as follows in scope of the appended claims.