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Inventor(s)

Bava; Felice Alessio

INCREASING EFFICIENCY OF SPATIAL ANALYSIS IN A BIOLOGICAL SAMPLE

Abstract

Disclosed herein are methods of amplifying an analyte in a biological sample using a bridging oligonucleotide that hybridizes to a captured analyte. The methods disclosed herein include steps of (a) contacting a biological sample with a substrate having capture probes comprising a capture domain and a spatial barcode; (b) hybridizing the analyte to the capture domain; and (c) contacting the analyte to a bridging oligonucleotide comprising (i) a capture-probe-binding sequence, and (ii) an analyte-binding sequence; (d) extending the bridging oligonucleotide; and (e) determining (i) all or a part of the sequence of the analyte, or a complement thereof, and (ii) the spatial barcode, or a complement thereof, and using the determined sequence of (i) and (ii) to determine the location of the analyte in the biological sample.

Inventors: Bava; Felice Alessio (Rome, IT)

Applicant: 10x Genomics, Inc. (Pleasanton, CA)

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a divisional application of U.S. patent application Ser. No. 18/340,511, filed Jun. 23, 2023, which is a continuation of U.S. patent application Ser. No. 17/167,559, filed Feb. 4, 2021, which claims priority to U.S. Provisional Patent Application No. 62/970,633, filed Feb. 5, 2020. The contents of this application are incorporated herein by reference in its entirety.

SEQUENCE LISTING

[0002] This application contains a Sequence Listing that has been submitted electronically as an XML file named “47706-0183003_SL_ST26.XML.” The XML file, created on Apr. 10, 2025, is 2,792 bytes in size. The material in the XML file is hereby incorporated by reference in its entirety.

BACKGROUND

[0003] Cells within a tissue of a subject have differences in cell morphology and/or function due to varied analyte levels (e.g., gene and/or protein expression) within the different cells. The specific position of a cell within a tissue (e.g., the cell's position relative to neighboring cells or the cell's position relative to the tissue microenvironment) can affect, e.g., the cell's morphology, differentiation, fate, viability, proliferation, behavior, and signaling and cross-talk with other cells in the tissue.

[0004] Spatial heterogeneity has been previously studied using techniques that only provide data for a small handful of analytes in the context of an intact tissue or a portion of a tissue, or provide a lot of analyte data for single cells, but fail to provide information regarding the position of the single cell in a parent biological sample (e.g., tissue sample).

[0005] Detecting and/or analyzing expression of genes in a biological sample can require methods for analyzing RNA in order to obtain spatial information about the target genes in the biological sample. Reverse transcription of mRNAs requires a primer to generate cDNA molecules. A primer can include a poly(T) oligonucleotide sequence that can function as a primer for reverse transcription while binding to the poly(A) tail of an mRNA molecule. However, in some instances, the mRNA-capturing oligonucleotides cannot be used for priming reverse transcription due to their specific spatial distribution or design. Therefore, there is a need for a primer can be used for priming reverse transcription of an mRNA that was captured by a different adjacent oligonucleotide.

SUMMARY

[0006] Disclosed herein are methods of determining the location of an analyte in a biological sample, the methods comprising: (a) contacting a biological sample with a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode; (b) hybridizing the analyte to the capture domain, thereby generating a capture analyte; and (c) contacting the captured analyte to a bridging oligonucleotide, wherein the bridging oligonucleotide comprises: (i) a capture-probe-binding sequence, and (ii) an analyte-binding sequence; (d) extending the bridging oligonucleotide using the analyte as a template to generate an extended capture probe comprising (i) the analyte, or a complement thereof, and (ii) the spatial barcode or a complement thereof; and (e) determining (i) all or a part of the sequence of the analyte, or a complement thereof, and (ii) all or a part of the sequence of the

spatial barcode, or a complement thereof, and using the determined sequence of (i) and (ii) to determine the location of the analyte in the biological sample.

[0007] In some embodiments, the bridging oligonucleotide further comprises (i) a flexible arm, and (ii) an annealing sequence comprising a functional domain, wherein the functional sequence is a primer sequence. In some embodiments, the flexible arm comprises a poly(T) sequence, poly(A) sequence, or a chemical group. In some embodiments, the bridging oligonucleotide comprises a 3'-OH end. In some embodiments, the capture-probe-binding sequence comprises a sequence that is complementary to the spatial barcode.

[0008] In some embodiments, contacting the captured analyte to the bridging oligonucleotide further comprises adding a capture probe primer sequence that hybridizes independently to the capture probe. In some embodiments, the methods further comprise extending the capture probe using the capture probe primer sequence, thereby generating an extended capture probe primer sequence. In some embodiments, the methods further comprise ligating the extended capture probe primer sequence to the bridging oligonucleotide. In some embodiments, contacting the captured analyte to the bridging oligonucleotide further comprises hybridizing one or more oligonucleotides that are complementary to adjacent sequences on the capture probe. In some embodiments, the methods further comprise ligating the one or more oligonucleotides that are complementary to adjacent sequences to one another and to the bridging oligonucleotide. In some embodiments, the step of extending comprises reverse transcription. In some embodiments, the methods further comprise cleaving the extended capture probe from the substrate, and determining (i) all or a part of the sequence of the analyte, or a complement thereof, and (ii) all or a part of the sequence of the spatial barcode, or a complement thereof, by sequencing.

[0009] In some embodiments, the biological sample is a tissue, a tissue section, an organ, an organism, or a cell culture sample. In some embodiments, the biological sample is a formalin-fixed, paraffin-embedded (FFPE) tissue sample, a frozen tissue sample, or a fresh tissue sample. In some embodiments, the analyte is selected from the group consisting of an RNA molecule, a DNA molecule, a protein, a small molecule, and a metabolite. In some embodiments, the analyte is mRNA. In some embodiments, the capture domain comprises a poly(T) sequence.

[0010] Provided herein are systems for spatial analysis comprising: (a) a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode; and (b) a plurality of bridging oligonucleotides, wherein a bridging oligonucleotide in the plurality of bridging oligonucleotides comprises (i) a capture-probe-binding sequence, (ii) an analyte-binding sequence, (iii) a flexible arm, and (iv) a sequence comprising a primer sequence. In some embodiments, the flexible arm comprises a poly(T) sequence, poly(A) sequence, or a chemical group.

[0011] Provided herein are kits comprising: (a) a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode; (b) a plurality of bridging oligonucleotides, wherein a bridging oligonucleotide in the plurality of bridging oligonucleotides comprises (i) a capture-probe-binding sequence and (ii) an analyte-binding sequence; and (c) instructions for performing the method of claim 1.

[0012] All publications, patents, patent applications, and information available on the internet and mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, patent application, or item of information was specifically and individually indicated to be incorporated by reference. To the extent publications, patents, patent applications, and items of information incorporated by reference contradict the disclosure contained in the specification, the specification is intended to supersede and/or take precedence over any such contradictory material.

[0013] Where values are described in terms of ranges, it should be understood that the description includes the disclosure of all possible sub-ranges within such ranges, as well as specific numerical values that fall within such ranges irrespective of whether a specific numerical value or specific

sub-range is expressly stated.

[0014] The term “each,” when used in reference to a collection of items, is intended to identify an individual item in the collection but does not necessarily refer to every item in the collection, unless expressly stated otherwise, or unless the context of the usage clearly indicates otherwise.

[0015] The singular form “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise. For example, the term “a cell” includes one or more cells, including mixtures thereof. “A and/or B” is used herein to include all of the following alternatives: “A”, “B”, “A or B”, and “A and B”.

[0016] Various embodiments of the features of this disclosure are described herein. However, it should be understood that such embodiments are provided merely by way of example, and numerous variations, changes, and substitutions can occur to those skilled in the art without departing from the scope of this disclosure. It should also be understood that various alternatives to the specific embodiments described herein are also within the scope of this disclosure.

Description

DESCRIPTION OF DRAWINGS

[0017] The following drawings illustrate certain embodiments of the features and advantages of this disclosure. These embodiments are not intended to limit the scope of the appended claims in any manner. Like reference symbols in the drawings indicate like elements.

[0018] FIG. 1 is a schematic diagram showing an example of a barcoded capture probe, as described herein.

[0019] FIG. 2 is a schematic illustrating a cleavable capture probe, wherein the cleaved capture probe can enter into a non-permeabilized cell and bind to target analytes within the sample.

[0020] FIG. 3 is a schematic diagram of an exemplary multiplexed spatially-barcoded feature.

[0021] FIG. 4 is a schematic diagram of an exemplary analyte capture agent.

[0022] FIG. 5 is a schematic diagram depicting an exemplary interaction between a feature-immobilized capture probe 524 and an analyte capture agent 526

[0023] FIGS. 6A-6C are schematics illustrating how streptavidin cell tags can be utilized in an array-based system to produce a spatially-barcoded cells or cellular contents.

[0024] FIG. 7 shows a schematic of capture of an mRNA molecule and hybridization of a primer (i.e., a bridging oligonucleotide).

[0025] FIGS. 8A and 8B show embodiments that include transcription of the capturing nucleotide, including a sequence with a spatial barcode (black ball) (FIG. 8A) and an embodiment using sequential ligation of multiple barcodes (FIG. 8B).

DETAILED DESCRIPTION

I. Introduction

[0026] Spatial analysis methods using capture probes and/or analyte capture agents provide information regarding the abundance and location of an analyte (e.g., a nucleic acid or protein). The efficiency of spatial analysis using arrays with capture probes depends, at least in part, on the density of the probes on the array or the density of the analytes captured on the array. That is, on how many capture probes can be printed on the surface of a slide or how many RNA molecules can be captured. Disclosed herein are methods and compositions for increasing the efficiency of spatial analysis by increasing the number of interactions between the capture probe and the analyte. In this way, analyte detection signal is increased, thus increasing the capturing efficiency, sensitivity, and the resolution of detection on the spatial array.

[0027] Traditionally, these methods identify a singular molecule at a location. Extending these methods to study interactions between two or more analytes would provide information on the interactions between two or more analytes at a location in a biological sample. Analyte capture

agents as provided herein comprises an analyte binding moiety affixed to an oligonucleotide. The oligonucleotide comprises a sequence that uniquely identifies the analyte and moiety. Further, nearby oligonucleotides affixed to a different moiety in a nearby location can be ligated to the first oligonucleotide and then can be detected using the spatial methods described herein. The methods disclosed herein thus provide the ability to study the interaction between two or more analytes in a biological sample.

[0028] Spatial analysis methodologies and compositions described herein can provide a vast amount of analyte and/or expression data for a variety of analytes within a biological sample at high spatial resolution, while retaining native spatial context. Spatial analysis methods and compositions can include, e.g., the use of a capture probe including a spatial barcode (e.g., a nucleic acid sequence that provides information as to the location or position of an analyte within a cell or a tissue sample (e.g., mammalian cell or a mammalian tissue sample) and a capture domain that is capable of binding to an analyte (e.g., a protein and/or a nucleic acid) produced by and/or present in a cell. Spatial analysis methods and compositions can also include the use of a capture probe having a capture domain that captures an intermediate agent for indirect detection of an analyte. For example, the intermediate agent can include a nucleic acid sequence (e.g., a barcode) associated with the intermediate agent. Detection of the intermediate agent is therefore indicative of the analyte in the cell or tissue sample.

[0029] Non-limiting aspects of spatial analysis methodologies and compositions are described in U.S. Pat. Nos. 10,774,374, 10,724,078, 10,480,022, 10,059,990, 10,041,949, 10,002,316, 9,879,313, 9,783,841, 9,727,810, 9,593,365, 8,951,726, 8,604,182, 7,709,198, U.S. Patent Application Publication Nos. 2020/239946, 2020/080136, 2020/0277663, 2020/024641, 2019/330617, 2019/264268, 2020/256867, 2020/224244, 2019/194709, 2019/161796, 2019/085383, 2019/055594, 2018/216161, 2018/051322, 2018/0245142, 2017/241911, 2017/089811, 2017/067096, 2017/029875, 2017/0016053, 2016/108458, 2015/000854, 2013/171621, WO 2018/091676, WO 2020/176788, Rodriques et al., Science 363 (6434): 1463-1467, 2019; Lee et al., Nat. Protoc. 10 (3): 442-458, 2015; Trejo et al., PLOS ONE 14 (2): e0212031, 2019; Chen et al., Science 348 (6233): aaa6090, 2015; Gao et al., BM C Biol. 15:50, 2017; and Gupta et al., Nature Biotechnol. 36:1197-1202, 2018; the Visium Spatial Gene Expression Reagent Kits User Guide (e.g., Rev C, dated June 2020), and/or the Visium Spatial Tissue Optimization Reagent Kits User Guide (e.g., Rev C, dated July 2020), both of which are available at the 10× Genomics Support Documentation website, and can be used herein in any combination. Further non-limiting aspects of spatial analysis methodologies and compositions are described herein.

[0030] Some general terminology that may be used in this disclosure can be found in Section (I)(b) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. Typically, a “barcode” is a label, or identifier, that conveys or is capable of conveying information (e.g., information about an analyte in a sample, a bead, and/or a capture probe). A barcode can be part of an analyte, or independent of an analyte. A barcode can be attached to an analyte. A particular barcode can be unique relative to other barcodes. For the purpose of this disclosure, an “analyte” can include any biological substance, structure, moiety, or component to be analyzed. The term “target” can similarly refer to an analyte of interest.

[0031] Analytes can be broadly classified into one of two groups: nucleic acid analytes, and non-nucleic acid analytes. Examples of non-nucleic acid analytes include, but are not limited to, lipids, carbohydrates, peptides, proteins, glycoproteins (N-linked or O-linked), lipoproteins, phosphoproteins, specific phosphorylated or acetylated variants of proteins, amidation variants of proteins, hydroxylation variants of proteins, methylation variants of proteins, ubiquitylation variants of proteins, sulfation variants of proteins, viral proteins (e.g., viral capsid, viral envelope, viral coat, viral accessory, viral glycoproteins, viral spike, etc.), extracellular and intracellular proteins, antibodies, and antigen binding fragments. In some embodiments, the analyte(s) can be

localized to subcellular location(s), including, for example, organelles, e.g., mitochondria, Golgi apparatus, endoplasmic reticulum, chloroplasts, endocytic vesicles, exocytic vesicles, vacuoles, lysosomes, etc. In some embodiments, analyte(s) can be peptides or proteins, including without limitation antibodies and enzymes. Additional examples of analytes can be found in Section (I)(c) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. In some embodiments, an analyte can be detected indirectly, such as through detection of an intermediate agent, for example, a connected probe (e.g., a ligation product) or an analyte capture agent (e.g., an oligonucleotide-conjugated antibody), such as those described herein.

[0032] A “biological sample” is typically obtained from the subject for analysis using any of a variety of techniques including, but not limited to, biopsy, surgery, and laser capture microscopy (LCM), and generally includes cells and/or other biological material from the subject. In some embodiments, a biological sample can be a tissue section. In some embodiments, a biological sample can be a fixed and/or stained biological sample (e.g., a fixed and/or stained tissue section). Non-limiting examples of stains include histological stains (e.g., hematoxylin and/or eosin) and immunological stains (e.g., fluorescent stains). In some embodiments, a biological sample (e.g., a fixed and/or stained biological sample) can be imaged. Biological samples are also described in Section (I)(d) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0033] In some embodiments, a biological sample is permeabilized with one or more permeabilization reagents. For example, permeabilization of a biological sample can facilitate analyte capture. Exemplary permeabilization agents and conditions are described in Section (I)(d) (ii)(13) or the Exemplary Embodiments Section of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0034] Array-based spatial analysis methods involve the transfer of one or more analytes from a biological sample to an array of features on a substrate, where each feature is associated with a unique spatial location on the array. Subsequent analysis of the transferred analytes includes determining the identity of the analytes and the spatial location of the analytes within the biological sample. The spatial location of an analyte within the biological sample is determined based on the feature to which the analyte is bound (e.g., directly or indirectly) on the array, and the feature's relative spatial location within the array.

[0035] A “capture probe” refers to any molecule capable of capturing (directly or indirectly) and/or labelling an analyte (e.g., an analyte of interest) in a biological sample. In some embodiments, the capture probe is a nucleic acid or a polypeptide. In some embodiments, the capture probe includes a barcode (e.g., a spatial barcode and/or a unique molecular identifier (UMI)) and a capture domain). In some embodiments, a capture probe can include a cleavage domain and/or a functional domain (e.g., a primer-binding site, such as for next-generation sequencing (NGS)).

[0036] FIG. 1 is a schematic diagram showing an exemplary capture probe, as described herein. As shown, the capture probe **102** is optionally coupled to a feature **101** by a cleavage domain **103**, such as a disulfide linker. The capture probe can include a functional sequence **104** that are useful for subsequent processing. The functional sequence **104** can include all or a part of sequencer specific flow cell attachment sequence (e.g., a P5 or P7 sequence), all or a part of a sequencing primer sequence, (e.g., a R1 primer binding site, a R2 primer binding site), or combinations thereof. The capture probe can also include a spatial barcode **105**. The capture probe can also include a unique molecular identifier (UMI) sequence **106**. While FIG. 1 shows the spatial barcode **105** as being located upstream (5') of UMI sequence **106**, it is to be understood that capture probes wherein UMI sequence **106** is located upstream (5') of the spatial barcode **105** is also suitable for use in any of the methods described herein. The capture probe can also include a capture domain **107** to facilitate capture of a target analyte. In some embodiments, the capture probe comprises one or more additional functional sequences that can be located, for example between the spatial barcode **105** and the UMI sequence **106**, between the UMI sequence **106** and the capture domain **107**, or following the capture domain **107**. The capture domain can have a sequence

complementary to a sequence of a nucleic acid analyte. The capture domain can have a sequence complementary to a connected probe described herein. The capture domain can have a sequence complementary to a capture handle sequence present in an analyte capture agent. The capture domain can have a sequence complementary to a splint oligonucleotide. A splint oligonucleotide, in addition to having a sequence complementary to a capture domain of a capture probe, can have a sequence of a nucleic acid analyte, a sequence complementary to a portion of a connected probe described herein, and/or a capture handle sequence described herein.

[0037] The functional sequences can generally be selected for compatibility with any of a variety of different sequencing systems, e.g., Ion Torrent Proton or PGM, Illumina sequencing instruments, PacBio, Oxford Nanopore, etc., and the requirements thereof. In some embodiments, functional sequences can be selected for compatibility with non-commercialized sequencing systems.

Examples of such sequencing systems and techniques, for which suitable functional sequences can be used, include (but are not limited to) Ion Torrent Proton or PGM sequencing, Illumina sequencing, PacBio SMRT sequencing, and Oxford Nanopore sequencing. Further, in some embodiments, functional sequences can be selected for compatibility with other sequencing systems, including non-commercialized sequencing systems.

[0038] In some embodiments, the spatial barcode **105** and functional sequences **104** is common to all of the probes attached to a given feature. In some embodiments, the UMI sequence **106** of a capture probe attached to a given feature is different from the UMI sequence of a different capture probe attached to the given feature.

[0039] FIG. 2 is a schematic illustrating a cleavable capture probe, wherein the cleaved capture probe can enter into a non-permeabilized cell and bind to analytes within the sample. The capture probe **201** contains a cleavage domain **202** a cell penetrating peptide **203**, a reporter molecule **204**, and a disulfide bond (—S—S—). **205** represents all other parts of a capture probe, for example a spatial barcode and a capture domain.

[0040] FIG. 3 is a schematic diagram of an exemplary multiplexed spatially-barcoded feature. In FIG. 3, the feature **301** can be coupled to spatially-barcoded capture probes, wherein the spatially-barcoded probes of a particular feature can possess the same spatial barcode, but have different capture domains designed to associate the spatial barcode of the feature with more than one target analyte. For example, a feature may be coupled to four different types of spatially-barcoded capture probes, each type of spatially-barcoded capture probe possessing the spatial barcode **302**. One type of capture probe associated with the feature includes the spatial barcode **302** in combination with a poly(T) capture domain **303**, designed to capture mRNA target analytes. A second type of capture probe associated with the feature includes the spatial barcode **302** in combination with a random N-mer capture domain **304** for gDNA analysis. A third type of capture probe associated with the feature includes the spatial barcode **302** in combination with a capture domain complementary to a capture handle sequence of an analyte capture agent of interest **305**. A fourth type of capture probe associated with the feature includes the spatial barcode **302** in combination with a capture domain that can specifically bind a nucleic acid molecule **306** that can function in a CRISPR assay (e.g., CRISPR/Cas9). While only four different capture probe-barcoded constructs are shown in FIG. 3, capture-probe barcoded constructs can be tailored for analyses of any given analyte associated with a nucleic acid and capable of binding with such a construct. For example, the schemes shown in FIG. 3 can also be used for concurrent analysis of other analytes disclosed herein, including, but not limited to: (a) mRNA, a lineage tracing construct, cell surface or intracellular proteins and metabolites, and gDNA; (b) mRNA, accessible chromatin (e.g., ATAC-seq, DNase-seq, and/or MNase-seq) cell surface or intracellular proteins and metabolites, and a perturbation agent (e.g., a CRISPR crRNA/sgRNA, TALEN, zinc finger nuclease, and/or antisense oligonucleotide as described herein); (c) mRNA, cell surface or intracellular proteins and/or metabolites, a barcoded labelling agent (e.g., the MHC multimers described herein), and a V(D)^J sequence of an immune cell receptor (e.g., T-cell receptor). In some embodiments, a perturbation agent can be a small

molecule, an antibody, a drug, an aptamer, a miRNA, a physical environmental (e.g., temperature change), or any other known perturbation agents. See, e.g., Section (II)(b) (e.g., subsections (i)-(vi)) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. Generation of capture probes can be achieved by any appropriate method, including those described in Section (II)(d)(ii) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0041] In some embodiments, more than one analyte type (e.g., nucleic acids and proteins) from a biological sample can be detected (e.g., simultaneously or sequentially) using any appropriate multiplexing technique, such as those described in Section (IV) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0042] In some embodiments, detection of one or more analytes (e.g., protein analytes) can be performed using one or more analyte capture agents. As used herein, an “analyte capture agent” refers to an agent that interacts with an analyte (e.g., an analyte in a biological sample) and with a capture probe (e.g., a capture probe attached to a substrate or a feature) to identify the analyte. In some embodiments, the analyte capture agent includes: (i) an analyte binding moiety (e.g., that binds to an analyte), for example, an antibody or antigen-binding fragment thereof; (ii) analyte binding moiety barcode; and (iii) a capture handle sequence. As used herein, the term “analyte binding moiety barcode” refers to a barcode that is associated with or otherwise identifies the analyte binding moiety. As used herein, the term “analyte capture sequence” or “capture handle sequence” refers to a region or moiety configured to hybridize to, bind to, couple to, or otherwise interact with a capture domain of a capture probe. In some embodiments, a capture handle sequence is complementary to a capture domain of a capture probe. In some cases, an analyte binding moiety barcode (or portion thereof) may be able to be removed (e.g., cleaved) from the analyte capture agent.

[0043] FIG. 4 is a schematic diagram of an exemplary analyte capture agent **402** comprised of an analyte-binding moiety **404** and an analyte-binding moiety barcode domain **408**. The exemplary analyte-binding moiety **404** is a molecule capable of binding to an analyte **406** and the analyte capture agent is capable of interacting with a spatially-barcoded capture probe. The analyte-binding moiety can bind to the analyte **406** with high affinity and/or with high specificity. The analyte capture agent can include an analyte-binding moiety barcode domain **408**, a nucleotide sequence (e.g., an oligonucleotide), which can hybridize to at least a portion or an entirety of a capture domain of a capture probe. The analyte-binding moiety barcode domain **408** can comprise an analyte binding moiety barcode and a capture handle sequence described herein. The analyte-binding moiety **404** can include a polypeptide and/or an aptamer. The analyte-binding moiety **404** can include an antibody or antibody fragment (e.g., an antigen-binding fragment).

[0044] FIG. 5 is a schematic diagram depicting an exemplary interaction between a feature-immobilized capture probe **524** and an analyte capture agent **526**. The feature-immobilized capture probe **524** can include a spatial barcode **508** as well as functional sequences **506** and a UMI **510**, as described elsewhere herein. The capture probe can also include a capture domain **512** that is capable of binding to an analyte capture agent **526**. The analyte capture agent **526** can include a functional sequence **518**, analyte binding moiety barcode **516**, and a capture handle sequence **514** that is capable of binding to the capture domain **512** of the capture probe **524**. The analyte capture agent can also include a linker **520** that allows the analyte binding moiety barcode domain **516** to couple to the analyte binding moiety **522**.

[0045] FIGS. 6A, 6B, and 6C are schematics illustrating how streptavidin cell tags can be utilized in an array-based system to produce a spatially-barcoded cell or cellular contents. For example, as shown in FIG. 6A, peptide-bound major histocompatibility complex (MHC) can be individually associated with biotin (β 2m) and bound to a streptavidin moiety such that the streptavidin moiety comprises multiple pMHC moieties. Each of these moieties can bind to a TCR such that the streptavidin binds to a target T-cell via multiple MHC/TCR binding interactions. Multiple

interactions synergize and can substantially improve binding affinity. Such improved affinity can improve labelling of T-cells and also reduce the likelihood that labels will dissociate from T-cell surfaces. As shown in FIG. 6B, a capture agent barcode domain **601** can be modified with streptavidin **602** and contacted with multiple molecules of biotinylated MHC **603** such that the biotinylated MHC **603** molecules are coupled with the streptavidin conjugated capture agent barcode domain **601**. The result is a barcoded MHC multimer complex **605**. As shown in FIG. 6B, the capture agent barcode domain sequence **601** can identify the MHC as its associated label and also includes optional functional sequences such as sequences for hybridization with other oligonucleotides. As shown in FIG. 6C, one example oligonucleotide is capture probe **606** that comprises a complementary sequence (e.g., rGrGrG corresponding to C C C), a barcode sequence and other functional sequences, such as, for example, a UMI, an adapter sequence (e.g., comprising a sequencing primer sequence (e.g., R1 or a partial R1 (“pR1”), R2), a flow cell attachment sequence (e.g., P5 or P7 or partial sequences thereof)), etc. In some cases, capture probe **606** may at first be associated with a feature (e.g., a gel bead) and released from the feature. In other embodiments, capture probe **606** can hybridize with a capture agent barcode domain **601** of the MHC-oligonucleotide complex **605**. The hybridized oligonucleotides (Spacer C C C and Spacer rGrGrG) can then be extended in primer extension reactions such that constructs comprising sequences that correspond to each of the two spatial barcode sequences (the spatial barcode associated with the capture probe, and the barcode associated with the MHC-oligonucleotide complex) are generated. In some cases, one or both of these corresponding sequences may be a complement of the original sequence in capture probe **606** or capture agent barcode domain **601**. In other embodiments, the capture probe and the capture agent barcode domain are ligated together. The resulting constructs can be optionally further processed (e.g., to add any additional sequences and/or for clean-up) and subjected to sequencing. As described elsewhere herein, a sequence derived from the capture probe **606** spatial barcode sequence may be used to identify a feature and the sequence derived from spatial barcode sequence on the capture agent barcode domain **601** may be used to identify the particular peptide MHC complex **604** bound on the surface of the cell (e.g., when using MHC-peptide libraries for screening immune cells or immune cell populations).

[0046] Additional description of analyte capture agents can be found in Section (II)(b)(ix) of WO 2020/176788 and/or Section (II)(b)(viii) U.S. Patent Application Publication No. 2020/0277663.

[0047] There are at least two methods to associate a spatial barcode with one or more neighboring cells, such that the spatial barcode identifies the one or more cells, and/or contents of the one or more cells, as associated with a particular spatial location. One method is to promote analytes or analyte proxies (e.g., intermediate agents) out of a cell and towards a spatially-barcoded array (e.g., including spatially-barcoded capture probes). Another method is to cleave spatially-barcoded capture probes from an array and promote the spatially-barcoded capture probes towards and/or into or onto the biological sample.

[0048] In some cases, capture probes may be configured to prime, replicate, and consequently yield optionally barcoded extension products from a template (e.g., a DNA or RNA template, such as an analyte or an intermediate agent (e.g., a connected probe (e.g., a ligation product) or an analyte capture agent), or a portion thereof), or derivatives thereof (see, e.g., Section (II)(b)(vii) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663 regarding extended capture probes). In some cases, capture probes may be configured to form a connected probe (e.g., a ligation product) with a template (e.g., a DNA or RNA template, such as an analyte or an intermediate agent, or portion thereof), thereby creating ligation products that serve as proxies for a template.

[0049] As used herein, an “extended capture probe” refers to a capture probe having additional nucleotides added to the terminus (e.g., 3' or 5' end) of the capture probe thereby extending the overall length of the capture probe. For example, an “extended 3' end” indicates additional nucleotides were added to the most 3' nucleotide of the capture probe to extend the length of the

capture probe, for example, by polymerization reactions used to extend nucleic acid molecules including templated polymerization catalyzed by a polymerase (e.g., a DNA polymerase or a reverse transcriptase). In some embodiments, extending the capture probe includes adding to a 3' end of a capture probe a nucleic acid sequence that is complementary to a nucleic acid sequence of an analyte or intermediate agent bound to the capture domain of the capture probe. In some embodiments, the capture probe is extended using reverse transcription. In some embodiments, the capture probe is extended using one or more DNA polymerases. The extended capture probes include the sequence of the capture probe and the sequence of the spatial barcode of the capture probe.

[0050] In some embodiments, extended capture probes are amplified (e.g., in bulk solution or on the array) to yield quantities that are sufficient for downstream analysis, e.g., via DNA sequencing. In some embodiments, extended capture probes (e.g., DNA molecules) act as templates for an amplification reaction (e.g., a polymerase chain reaction).

[0051] Additional variants of spatial analysis methods, including in some embodiments, an imaging step, are described in Section (II)(a) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. Analysis of captured analytes (and/or intermediate agents or portions thereof), for example, including sample removal, extension of capture probes, sequencing (e.g., of a cleaved extended capture probe and/or a cDNA molecule complementary to an extended capture probe), sequencing on the array (e.g., using, for example, in situ hybridization or in situ ligation approaches), temporal analysis, and/or proximity capture, is described in Section (II)(g) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. Some quality control measures are described in Section (II)(h) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0052] Spatial information can provide information of biological and/or medical importance. For example, the methods and compositions described herein can allow for: identification of one or more biomarkers (e.g., diagnostic, prognostic, and/or for determination of efficacy of a treatment) of a disease or disorder; identification of a candidate drug target for treatment of a disease or disorder; identification (e.g., diagnosis) of a subject as having a disease or disorder; identification of stage and/or prognosis of a disease or disorder in a subject; identification of a subject as having an increased likelihood of developing a disease or disorder; monitoring of progression of a disease or disorder in a subject; determination of efficacy of a treatment of a disease or disorder in a subject; identification of a patient subpopulation for which a treatment is effective for a disease or disorder; modification of a treatment of a subject with a disease or disorder; selection of a subject for participation in a clinical trial; and/or selection of a treatment for a subject with a disease or disorder.

[0053] Spatial information can provide information of biological importance. For example, the methods and compositions described herein can allow for: identification of transcriptome and/or proteome expression profiles (e.g., in healthy and/or diseased tissue); identification of multiple analyte types in close proximity (e.g., nearest neighbor analysis); determination of up-and/or down-regulated genes and/or proteins in diseased tissue; characterization of tumor microenvironments; characterization of tumor immune responses; characterization of cells types and their co-localization in tissue; and identification of genetic variants within tissues (e.g., based on gene and/or protein expression profiles associated with specific disease or disorder biomarkers).

[0054] Typically, for spatial array-based methods, a substrate functions as a support for direct or indirect attachment of capture probes to features of the array. A "feature" is an entity that acts as a support or repository for various molecular entities used in spatial analysis. In some embodiments, some or all of the features in an array are functionalized for analyte capture. Exemplary substrates are described in Section (II)(c) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. Exemplary features and geometric attributes of an array can be found in Sections (II)(d)(i), (II)(d)(iii), and (II)(d)(iv) of WO 2020/176788 and/or U.S. Patent Application Publication

No. 2020/0277663.

[0055] Generally, analytes and/or intermediate agents (or portions thereof) can be captured when contacting a biological sample with a substrate including capture probes (e.g., a substrate with capture probes embedded, spotted, printed, fabricated on the substrate, or a substrate with features (e.g., beads, wells) comprising capture probes). As used herein, “contact,” “contacted,” and/or “contacting,” a biological sample with a substrate refers to any contact (e.g., direct or indirect) such that capture probes can interact (e.g., bind covalently or non-covalently (e.g., hybridize)) with analytes from the biological sample. Capture can be achieved actively (e.g., using electrophoresis) or passively (e.g., using diffusion). Analyte capture is further described in Section (II)(e) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0056] In some cases, spatial analysis can be performed by attaching and/or introducing a molecule (e.g., a peptide, a lipid, or a nucleic acid molecule) having a barcode (e.g., a spatial barcode) to a biological sample (e.g., to a cell in a biological sample). In some embodiments, a plurality of molecules (e.g., a plurality of nucleic acid molecules) having a plurality of barcodes (e.g., a plurality of spatial barcodes) are introduced to a biological sample (e.g., to a plurality of cells in a biological sample) for use in spatial analysis. In some embodiments, after attaching and/or introducing a molecule having a barcode to a biological sample, the biological sample can be physically separated (e.g., dissociated) into single cells or cell groups for analysis. Some such methods of spatial analysis are described in Section (III) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663.

[0057] In some cases, spatial analysis can be performed by detecting multiple oligonucleotides that hybridize to an analyte. In some instances, for example, spatial analysis can be performed using RNA-templated ligation (RTL). Methods of RTL have been described previously. See, e.g., Credle et al., *Nucleic Acids Res.* 2017 Aug. 21;45(14):e128. Typically, RTL includes hybridization of two oligonucleotides to adjacent sequences on an analyte (e.g., an RNA molecule, such as an mRNA molecule). In some instances, the oligonucleotides are DNA molecules. In some instances, one of the oligonucleotides includes at least two ribonucleic acid bases at the 3' end and/or the other oligonucleotide includes a phosphorylated nucleotide at the 5' end. In some instances, one of the two oligonucleotides includes a capture domain (e.g., a poly(A) sequence, a non-homopolymeric sequence). After hybridization to the analyte, a ligase (e.g., SplintR ligase) ligates the two oligonucleotides together, creating a connected probe (e.g., a ligation product). In some instances, the two oligonucleotides hybridize to sequences that are not adjacent to one another. For example, hybridization of the two oligonucleotides creates a gap between the hybridized oligonucleotides. In some instances, a polymerase (e.g., a DNA polymerase) can extend one of the oligonucleotides prior to ligation. After ligation, the connected probe (e.g., a ligation product) is released from the analyte. In some instances, the connected probe (e.g., a ligation product) is released using an endonuclease (e.g., RNase H). The released connected probe (e.g., a ligation product) can then be captured by capture probes (e.g., instead of direct capture of an analyte) on an array, optionally amplified, and sequenced, thus determining the location and optionally the abundance of the analyte in the biological sample.

[0058] During analysis of spatial information, sequence information for a spatial barcode associated with an analyte is obtained, and the sequence information can be used to provide information about the spatial distribution of the analyte in the biological sample. Various methods can be used to obtain the spatial information. In some embodiments, specific capture probes and the analytes they capture are associated with specific locations in an array of features on a substrate. For example, specific spatial barcodes can be associated with specific array locations prior to array fabrication, and the sequences of the spatial barcodes can be stored (e.g., in a database) along with specific array location information, so that each spatial barcode uniquely maps to a particular array location.

[0059] Alternatively, specific spatial barcodes can be deposited at predetermined locations in an

array of features during fabrication such that at each location, only one type of spatial barcode is present so that spatial barcodes are uniquely associated with a single feature of the array. Where necessary, the arrays can be decoded using any of the methods described herein so that spatial barcodes are uniquely associated with array feature locations, and this mapping can be stored as described above.

[0060] When sequence information is obtained for capture probes and/or analytes during analysis of spatial information, the locations of the capture probes and/or analytes can be determined by referring to the stored information that uniquely associates each spatial barcode with an array feature location. In this manner, specific capture probes and captured analytes are associated with specific locations in the array of features. Each array feature location represents a position relative to a coordinate reference point (e.g., an array location, a fiducial marker) for the array. Accordingly, each feature location has an “address” or location in the coordinate space of the array.

[0061] Some exemplary spatial analysis workflows are described in the Exemplary Embodiments section of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. See, for example, the Exemplary embodiment starting with “In some non-limiting examples of the workflows described herein, the sample can be immersed . . . ” of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. See also, e.g., the Visium Spatial Gene Expression Reagent Kit's User Guide (e.g., Rev C, dated June 2020) , and/or the Visium Spatial Tissue Optimization Reagent Kits User Guide (e.g., Rev C, dated July 2020).

[0062] In some embodiments, spatial analysis can be performed using dedicated hardware and/or software, such as any of the systems described in Sections (II)(e)(ii) and/or (V) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663, or any of one or more of the devices or methods described in Sections Control Slide for Imaging, Methods of Using Control Slides and Substrates for, Systems of Using Control Slides and Substrates for Imaging, and/or Sample and Array Alignment Devices and Methods, Informational labels of WO 2020/123320.

[0063] Suitable systems for performing spatial analysis can include components such as a chamber (e.g., a flow cell or sealable, fluid-tight chamber) for containing a biological sample. The biological sample can be mounted for example, in a biological sample holder. One or more fluid chambers can be connected to the chamber and/or the sample holder via fluid conduits, and fluids can be delivered into the chamber and/or sample holder via fluidic pumps, vacuum sources, or other devices coupled to the fluid conduits that create a pressure gradient to drive fluid flow. One or more valves can also be connected to fluid conduits to regulate the flow of reagents from reservoirs to the chamber and/or sample holder.

[0064] The systems can optionally include a control unit that includes one or more electronic processors, an input interface, an output interface (such as a display), and a storage unit (e.g., a solid state storage medium such as, but not limited to, a magnetic, optical, or other solid state, persistent, writeable and/or re-writeable storage medium). The control unit can optionally be connected to one or more remote devices via a network. The control unit (and components thereof) can generally perform any of the steps and functions described herein. Where the system is connected to a remote device, the remote device (or devices) can perform any of the steps or features described herein. The systems can optionally include one or more detectors (e.g., CCD, CMOS) used to capture images. The systems can also optionally include one or more light sources (e.g., LED-based, diode-based, lasers) for illuminating a sample, a substrate with features, analytes from a biological sample captured on a substrate, and various control and calibration media.

[0065] The systems can optionally include software instructions encoded and/or implemented in one or more of tangible storage media and hardware components such as application specific integrated circuits. The software instructions, when executed by a control unit (and in particular, an electronic processor) or an integrated circuit, can cause the control unit, integrated circuit, or other component executing the software instructions to perform any of the method steps or functions

described herein.

[0066] In some cases, the systems described herein can detect (e.g., register an image) the biological sample on the array. Exemplary methods to detect the biological sample on an array are described in PCT Application No. 2020/061064 and/or U.S. patent application Ser. No. 16/951,854.

[0067] Prior to transferring analytes from the biological sample to the array of features on the substrate, the biological sample can be aligned with the array. Alignment of a biological sample and an array of features including capture probes can facilitate spatial analysis, which can be used to detect differences in analyte presence and/or level within different positions in the biological sample, for example, to generate a three-dimensional map of the analyte presence and/or level. Exemplary methods to generate a two-and/or three-dimensional map of the analyte presence and/or level are described in PCT Application No. 2020/053655 and spatial analysis methods are generally described in WO 2020/061108 and/or U.S. patent application Ser. No. 16/951,864.

[0068] In some cases, a map of analyte presence and/or level can be aligned to an image of a biological sample using one or more fiducial markers, e.g., objects placed in the field of view of an imaging system which appear in the image produced, as described in the Substrate Attributes Section, Control Slide for Imaging Section of WO 2020/123320, PCT Application No. 2020/061066, and/or U.S. patent application Ser. No. 16/951,843. Fiducial markers can be used as a point of reference or measurement scale for alignment (e.g., to align a sample and an array, to align two substrates, to determine a location of a sample or array on a substrate relative to a fiducial marker) and/or for quantitative measurements of sizes and/or distances.

[0069] The sandwich process is described in PCT Patent Application Publication No. WO 2020/123320, which is incorporated by reference in its entirety.

II. Compositions for Copying of Captured Analytes or Analyte Derivatives

[0070] Provided herein are methods and compositions for increasing the efficiency of spatial detection of one or more analytes (i.e., a nucleic acid or a non-nucleic acid). In order to determine the abundance and the location of an analyte in a biological sample, a user performs an amplification or copying (e.g., reverse transcription) process after an analyte is captured by a capture probe. A primer sequence is usually included in part of the capture probe, and sometimes the primer sequence and the capture domain sequence function for both analyte binding and for priming the amplification or copying process. Thus, in order to increase efficiency of the copying process, disclosed herein are compositions and methods that utilize an adjacent oligonucleotide (e.g., a “bridging oligonucleotide”) that can hybridize to the capture probe and facilitate copying of the captured analyte.

[0071] Provided herein are methods of determining abundance and location of an analyte in a biological sample, the method comprising (a) contacting a biological sample with a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode; (b) hybridizing the analyte to the capture domain, thereby generating a capture analyte; and (c) contacting the captured analyte to a bridging oligonucleotide, wherein the bridging oligonucleotide comprises (i) a capture-probe-binding sequence, and (ii) an analyte-binding sequence; (d) extending the bridging oligonucleotide using the analyte as a template to generate an extended capture probe comprising (i) the analyte, or a complement thereof, and (ii) the spatial barcode or a complement thereof; and (e) determining (i) all or a part of the sequence of the analyte, or a complement thereof, and (ii) all or a part of the sequence of the spatial barcode, or a complement thereof, and using the determined sequence of (i) and (ii) to determine the abundance and the location of the analyte in the biological sample.

[0072] The methods provided herein also include methods for performing reverse transcription on biological analytes (e.g., mRNA) captured on a substrate (e.g., capture probe array). Further provided are methods for using bridging oligonucleotides for capturing and hybridizing a biological analyte (e.g., mRNA) that is captured by a capture probe on the substrate. In some embodiments, the bridging oligonucleotide comprises a capture-probe-binding sequence, a flexible

arm, an analyte-binding sequence, and an annealing sequence. In some embodiments, the bridging oligonucleotide further comprises at least one, at least two, at least three, at least four, or at least five, or more barcode sequences.

[0073] Additional embodiments of the disclosure are further provided.

(a) Bridging Oligonucleotides

[0074] Disclosed herein are compositions and methods of detecting and amplifying a biological analyte using a bridging oligonucleotide. A “bridging oligonucleotide” refers to a nucleic acid sequence that aids in amplification priming the analyte for copying or amplification. In some instances, the bridging oligonucleotide comprises a 3'-OH end that is used as a primer for starting the reverse transcription of an mRNA captured by a different adjacent oligonucleotide (e.g., a poly(T) sequence). In some embodiments, the bridging oligonucleotide is an RNA molecule. In some embodiments, the bridging oligonucleotide is a DNA molecule.

[0075] In some embodiments, the bridging oligonucleotide includes a capture-probe-binding sequence, a flexible arm, an analyte-binding sequence, an annealing sequence, and any combination thereof. In some embodiments, a bridging oligonucleotide includes a sequence that is at about 5 nucleotides to about 150 nucleotides (e.g., about 5, about 10, about 15, about 20, about 25, about 30, about 35, about 40, about 45, about 50, about 55, about 60, about 65, about 70, about 75, about 80, about 85, about 90, about 95, about 100, about 105, about 110, about 115, about 120, about 125, about 130, about 135, about 140, about 145, or about 150 nucleotides) in length.

[0076] In some embodiments, the capture-probe-binding sequence of the bridging oligonucleotide is a nucleic acid sequence that hybridizes to a capture probe on an array. In some instances, the capture-probe-binding sequence hybridizes to the spatial barcode sequence of the probe. In some embodiments, the capture-probe-binding sequence is located at the 5' end of the bridging oligonucleotide. In some instances, the capture-probe-binding sequence is located at the 3' end of the bridging oligonucleotide.

[0077] In some embodiments, the capture-probe-binding sequence is at least 70% identical (e.g., at least 75% identical, at least 80% identical, at least 85% identical, at least 90% identical, at least 95% identical, or at least 99% identical) to a portion of the capture probe. In some embodiments, the capture-probe-binding sequence is at least 100% identical to a portion of the capture probe. In some embodiments, the capture-probe-binding sequence is about 5 nucleotides to about 50 nucleotides (e.g., about 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 nucleotides) in length.

[0078] In some embodiments, a bridging oligonucleotide includes a flexible arm. A flexible arm is a nucleic acid sequence that allows the bridging oligonucleotide to extend its reach to adjacent mRNAs. In some embodiments, the flexible arm includes a sequence of nucleotides, including a 1-mer, 2-mer, 3-mer or longer sequence. In some embodiments, the flexible arm can be a poly(A) sequence. In some embodiments, the flexible arm can be a poly(T) sequence. In some embodiments, the flexible arm can be a chemical group. In some embodiments, and without limitation, a chemical group can be one or more of a hydroxyl group, an amine group, a functional amine group, a chemically modified amine group. In some embodiments, the flexible arm 5 nucleotides to about 50 nucleotides (e.g., about 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 nucleotides) in length.

[0079] In some embodiments, a bridging oligonucleotide includes an analyte-binding sequence. An analyte-binding sequence is a nucleic acid sequence that hybridizes to an analyte. In some instances, the analyte-binding sequence is a sequence that hybridizes to a target sequence within the target mRNA. In some embodiments, the bridging oligonucleotide includes a sequence-specific target-binding sequence. For example, the bridging oligonucleotide can be capable of binding selectively to a desired sub-type of nucleic acid molecule (e.g. mRNA, rRNA, RNA, SRP RNA,

tmRNA, snRNA, scaRNA, gRNA, RNase P, RNase MRP, TERC, SL RNA, aRNA, cis-NAT, crRNA, IncRNA, miRNA, piRNA, siRNA, shRNA, tasiRNA, rasiRNA, 7SK, eRNA, ncRNA or other types of RNA). In some embodiments, the analyte-binding sequence hybridizes to an mRNA analyte.

[0080] In some embodiments, the analyte-binding sequence is at least 70% identical (e.g., at least 75% identical, at least 80% identical, at least 85% identical, at least 90% identical, at least 95% identical, or at least 99% identical) to a portion of an analyte. In some embodiments, the analyte-binding sequence is at least 100% identical to a portion of the analyte. In some embodiments, the analyte-binding sequence is about 5 nucleotides to about 50 nucleotides (e.g., about 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 nucleotides) in length.

[0081] In some embodiments, a bridging oligonucleotide includes an annealing sequence. An annealing sequence is a nucleic acid sequence that is designed to ensure that it anneals to the adjacent mRNA. In some embodiments, the annealing sequence serves as a primer for reverse-transcription of the analyte. In some embodiments, the annealing sequence is 3' to the flexible arm. In some embodiments, the annealing sequence includes a sequence of nucleotides, including a 1-mer, 2-mer, 3-mer or longer sequence. In some embodiments, the annealing sequence can be a sequence of VNN sequence (V is A, C or G and N is any nucleotide (e.g., A, C, G, T, U)) that will anneal to the adjacent mRNA. In some embodiments, the flexible arm can be designed using a specific sequence of nucleotides.

[0082] In some instances, the bridging oligonucleotide further comprises a primer sequence at its 5' end. In this instance, the primer can be used for reverse transcription that results in a copied sequence that includes the entire bridging oligonucleotide (i.e., any of the components described above) and a complement of the analyte, or a portion thereof.

[0083] In some embodiments, the bridging oligonucleotide includes, in order from 5' to 3', a capture-probe-binding sequence, a flexible arm, an analyte-binding sequence, and an annealing sequence. In some embodiments, the bridging oligonucleotide includes, in order from 5' to 3', an annealing sequence, a capture-probe-binding sequence, a flexible arm, and an analyte-binding sequence. It is appreciated that the annealing sequence can be located anywhere on the bridging oligonucleotide. In other words, some embodiments include reordering the 5' to 3' sequence order of the capture-probe-binding sequence, a flexible arm, an analyte-binding sequence, and an annealing sequence.

[0084] Referring to FIG. 7, the method herein includes a substrate **701** that has a plurality of capture probes thereon, with a capture probe **702** having a capture domain **703** and **706** and a bridging oligonucleotide complementary sequence **705**. In some instances, the bridging oligonucleotide complementary sequence **705** includes a spatial barcode. After hybridization of an analyte **708** (or **710**) to the capture domain **703** (or **706**) via e.g., a poly(A) tail **709** (or **711**), a bridging oligonucleotide comprising a capture-probe-binding sequence **714** and an analyte-binding sequence **712** is added to the substrate. In some instances, the bridging oligonucleotide also includes a flexible arm **713** that allows for the capture-probe-binding sequence **714** and the analyte-binding sequence **712** to bind to their respective complementary sequences.

[0085] In some instances, the capture probe **702** includes multiple capture domains (e.g., **703** and **706**) that allow for capture of multiple analytes (e.g., **708** and **710**).

[0086] In some embodiments, a bridging oligonucleotide includes optional functional sequences, such as, without limitation, a PCR handle, a sequencing priming site, a domain for hybridizing to another nucleic acid molecule, and combinations thereof. In some embodiments, a bridging oligonucleotide includes one or more optional sequences and/or one or more barcode sequences (e.g., one or more spatial barcodes and/or one or more UMIs). In some embodiments, the one or more barcode sequences can be ligated to the bridging oligonucleotide for further processing by methods for spatial profiling (e.g., sequencing) as described herein.

(b) Biological Samples and Analytes

[0087] Methods disclosed herein can be performed on any type of sample. In some embodiments, the sample is a fresh tissue. In some instances, the biological sample is a tissue, a tissue section, an organ, an organism, or a cell culture sample. In some instances, the biological sample is a formalin-fixed, paraffin-embedded (FFPE) sample, a frozen sample, or a fresh sample.

[0088] In some embodiments, the analyte includes one or more of RNA, DNA, a protein, a small molecule, and a metabolite. In some embodiments, the analyte (e.g., target analyte) is a single-stranded oligonucleotide. In some embodiments, the single-stranded oligonucleotide is RNA. In some embodiments, the RNA is mRNA. In some embodiments, the mRNA is an mRNA of interest. In some embodiments, the multiple target analytes are detected. The multiple targets can, in some instances, include sequences that have at least 80%, at least 85%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99% sequence identity to each other. In some instances, the multiple targets each include one or more conserved sequences. In some instances, the multiple targets are mRNAs that encode for proteins that have a similar function. In some instances, the multiple targets are mRNAs that encode for proteins that function in the same or a similar cellular pathway.

[0089] In settings where the analyte is a nucleic acid, a capture probe such as those described in FIGS. 1-3 can be used to detect the analyte. In settings where the analyte is a protein, a capture probe such as those described in FIGS. 1-3 can be used to detect the oligonucleotide affixed to the analyte binding moiety as shown in FIG. 4. Capture probes that detect nucleic acids (e.g., mRNA) and capture probes that detect oligonucleotides affixed to the analyte binding moieties are disclosed in WO 2020/176788 and U.S. Patent Application Publication No. 2020/0277663, each of which is incorporated by reference in its entirety.

[0090] Subjects from which biological samples can be obtained can be healthy or asymptomatic individuals, individuals that have or are suspected of having a disease (e.g., cancer) or a pre-disposition to a disease, and/or individuals that are in need of therapy or suspected of needing therapy. In some instances, the biological sample can include one or more diseased cells. A diseased cell can have altered metabolic properties, gene expression, protein expression, and/or morphologic features. Examples of diseases include inflammatory disorders, metabolic disorders, nervous system disorders, and cancer. In some instances, the biological sample includes cancer or tumor cells. Cancer cells can be derived from solid tumors, hematological malignancies, cell lines, or obtained as circulating tumor cells. In some instances, the biological sample is a heterogeneous sample. In some instances, the biological sample is a heterogeneous sample that includes tumor or cancer cells and/or stromal cells.

[0091] In some embodiments, the biological sample is from a human subject.

[0092] FFPE samples generally are heavily cross-linked and fragmented, and therefore this type of sample allows for limited RNA recovery using conventional detection techniques. In certain embodiments, methods of targeted RNA capture provided herein are less affected by RNA degradation associated with FFPE fixation than other methods (e.g., methods that take advantage of oligo-dT capture and reverse transcription of mRNA). In certain embodiments, methods provided herein enable sensitive measurement of specific genes of interest that otherwise might be missed with a whole transcriptomic approach.

[0093] In some instances, FFPE samples are stained (e.g., using H & E or immunofluorescence). The methods disclosed herein are compatible with H & E and IF will allow for morphological context overlaid with transcriptomic analysis. However, depending on the need some samples may be stained with only a nuclear stain, such as staining a sample with only hematoxylin and not eosin, or DAPI, etc. when location of a cell nucleus is needed.

[0094] In some embodiments, a biological sample (e.g. tissue sample section) can be fixed with methanol, stained with hematoxylin and eosin, and imaged. In some embodiments, fixing, staining, and imaging occurs before one or more probes are hybridized to the sample. Some embodiments of

any of the workflows described herein can further include a destaining step (e.g., a hematoxylin and eosin destaining step), after imaging of the sample and prior to permeabilizing the sample. For example, destaining can be performed by performing one or more (e.g., one, two, three, four, or five) washing steps (e.g., one or more (e.g., one, two, three, four, or five) washing steps performed using a buffer including HCl). The images can be used to map spatial gene expression patterns back to the biological sample. A permeabilization enzyme can be used to permeabilize the biological sample directly on the slide.

[0095] In some embodiments, the FFPE sample is deparaffinized, permeabilized, equilibrated, and blocked before target probe oligonucleotides are added. In some embodiments, deparaffinization can include the use of xylenes. In some embodiments, deparaffinization includes multiple washes with xylenes. In some embodiments, deparaffinization includes multiple washes with xylenes followed by removal of xylenes using multiple rounds of graded alcohol washes followed by washing the sample with water. In some aspects, the water is deionized water. In some embodiments, equilibrating and blocking includes incubating the sample in a pre-Hyb buffer. In some embodiments, the pre-Hyb buffer includes yeast tRNA. In some embodiments, permeabilizing a sample includes washing the sample with a phosphate buffer. In some embodiments, the buffer is PBS. In some embodiments, the buffer is PBST.

(c) Substrates and Capture Probes

[0096] In some embodiments, disclosed herein are methods that include any of the arrays (e.g., substrate) as described in this application. In some embodiments, the substrate can include any bead or plurality of beads as disclosed herein. In some embodiments, a plurality of capture probes is tethered to the surface of an array. In some embodiments, the probes in the plurality are oligonucleotides. In some embodiments, the oligonucleotide is single-stranded.

[0097] In some aspects, arrays include a plurality of capture probes that bind to one or more biological targets in a sample. The capture probes can be directly or indirectly attached to a substrate. The capture probe can be or include, for example, DNA or RNA. In some aspects, the capture probes on an array can be immobilized, e.g., attached or bound, to the array via their 5' or 3' ends, depending on the chemical matrix of the array. In some aspects, the probes are attached via a 3' linkage, thereby leaving a free 5' end. In some aspects, the probes are attached via a 5' linkage, thereby leaving a free 3' end. In some aspects, the probes are immobilized indirectly. For example, a probe can be attached to a bead, which bead can be deposited on a substrate. A capture probe as disclosed in this section can include any of the various components of a capture probe as provided throughout this disclosure (e.g., spatial barcodes, UMIs, functional domains, cleavage domains, etc.).

[0098] In some aspects, a capture probe or plurality of capture probes interact with an analyte specific for a particular species or organism (e.g., host or pathogen). In some aspects, the probe or plurality of probes can be used to detect a viral, bacterial, or plant protein or nucleic acid. In some aspects, the capture probe or plurality of capture probes can be used to detect the presence of a pathogen (e.g., bacteria or virus) in the biological sample. In some aspects, the capture probe or plurality of capture probes can be used to detect the expression of a particular nucleic acid associated with a pathogen (e.g., presence of 16S ribosomal RNA or Human Immunodeficiency Virus (HIV) RNA in a human sample).

[0099] In some embodiments, a capture probe in the plurality of capture probes includes a capture domain sequence. In some embodiments, the capture probe includes more than one capture domain sequence. For example, in some embodiments, the capture probe includes at least 2, at least 3, at least 4, or at least five capture probe domain sequences. In some embodiments, there are the same number of capture probe domain sequences in each of the probes on an array. In some embodiments, the capture probe domain sequences in each of the probes varies among the probes in the plurality.

[0100] In some embodiments, the capture domain is designed to detect one or more specific

analytes of interest. For example, a capture domain can be designed so that it comprises a sequence that is complementary or substantially complementary to one analyte of interest. Thus, the presence of a single analyte can be detected. Alternatively, the capture domain can be designed so that it comprises a sequence that is complementary or substantially complementary to a conserved region of multiple related analytes. In some instances, the multiple related analytes are analytes that function in the same or similar cellular pathways or that have conserved homology and/or function. The design of the capture probe can be determined based on the intent of the user and can be any sequence that can be used to detect an analyte of interest. In some embodiments, the capture domain sequence can therefore be random, semi-random, defined or combinations thereof, depending on the target analyte(s) of interest.

[0101] In some embodiments, the capture domain includes a poly(T) sequence that allows a poly(A) sequence of an mRNA transcript to hybridize to the probe. In some embodiments, there is one poly(T) sequence on a probe. In some embodiments, there are at least two, at least three, at least four, at least five, or more poly(T) sequences on an individual probe in a plurality of probes. In some embodiments, there are the same number of poly(T) sequences in each of the probes on an array. In some embodiments, the number of poly(T) sequences in each of the probes varies among the probes in the plurality.

[0102] In some instances, a probe in the plurality includes a sequence that is complementary to the sequence of a particular target of interest. In some embodiments, a capture probe includes a capture domain that is capable of binding to one analyte. In some embodiments, a capture domain can bind to an analyte that is about 80% identical, about 85% identical, about 90% identical, about 95% identical, about 96% identical, about 97% identical, about 98% identical, about 99% identical, 100% identical to the target analyte. In some embodiments, a capture domain can bind to a conserved region of an analyte. In some embodiments, conserved regions of an analyte are about 80% identical, about 85% identical, about 90% identical, about 95% identical, about 96% identical, about 97% identical, about 98% identical, about 99% identical, 100% identical to the analyte.

[0103] In some embodiments, a capture probe includes a capture domain that is capable of binding to more than one analyte. In some embodiments, a capture domain can bind to one or more analytes that are about 80% identical, about 85% identical, about 90% identical, about 95% identical, about 96% identical, about 97% identical, about 98% identical, about 99% identical, 100% identical to an analyte of interest. In some aspects, the capture probe can bind to an analyte that is about 80% identical, about 85% identical, about 90% identical, about 95% identical, about 96% identical, about 97% identical, about 98% identical, or about 99% identical to each other. In some embodiments, a capture domain can bind to a conserved region of one or more analytes, in which the conserved regions are about 80% identical, about 85% identical, about 90% identical, about 95% identical, about 96% identical, about 97% identical, about 98% identical, about 99% identical, 100% identical to the analyte.

[0104] In some aspects, a capture probe or plurality of capture probes interacts with two or more analytes (e.g., nucleic acids or proteins) that are not similar in sequence and/or do not share a conserved domain. In some embodiments, a capture probe includes two or more capture domains, each of which interacts with a different analyte. In such embodiments, members of the two or more capture domains can be adjacent to each other in the capture probe and/or members of the two or more capture domains can be separated from each other in the capture probe by one or more domains (e.g., nucleic acid domains). For example, in some aspects, the sets of analytes that are detected include mutational changes in the targeted nucleic acids or proteins. In some aspects, the capture probe or plurality of capture probes detects sets of nucleic acids or proteins (e.g., non-homologous nucleic acids or proteins) that are individually mutated during a pathogenic state. In some aspects, the pathogenic state is cancer.

[0105] In some aspects, a capture probe or plurality of capture probes include capture domains that can be used to detect analytes that are typically detected using diagnostic panels. In some aspects,

the capture probe or plurality of capture probes are used to detect changes in one or more analytes. In some aspects, the analyte changes include one or more of increased analyte expression, decreased analyte expression, mutated nucleic acid sequences, or any combination thereof. In some aspects, the changes in the analytes are associated with and/or lead to manifestation of a pathogenic state in a subject. In some aspects, the detected changes are compared to a reference analyte or analytes.

[0106] In some embodiments, the capture domain is located at the 3' end of the capture probe. In some instances, the 3' end of the capture probe can be extended using methods described herein. For example, the capture domain can include a nucleic acid sequence (e.g., a poly(T) sequence) that is capable of hybridizing to a poly(A) tail of an mRNA present in the biological sample.

[0107] In some embodiments, the capture domain can have a GC content between 1-100%, e.g., 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%, 35%, 40%, 45%, 50%, 60%, 70%, 80%, 90% or 100%. In some embodiments, the capture domain has a GC content of at least 30%.

[0108] In some embodiments, the probe includes a sequence for hybridization of another oligonucleotide (the "bridging oligonucleotide," discussed below). In some instances, a probe in the plurality includes a sequence that is complementary to the sequence of the bridging oligonucleotide. In some embodiments, a capture probe can bind to a bridging oligonucleotide that is about 80% identical, about 85% identical, about 90% identical, about 95% identical, about 96% identical, about 97% identical, about 98% identical, about 99% identical, 100% identical to the bridging oligonucleotide.

[0109] In some embodiments, the section of the probe that hybridizes to the bridging oligonucleotide includes a spatial barcode sequence. In some embodiments, the section of the probe that hybridizes to the bridging oligonucleotide includes more than one spatial barcode sequence. In some embodiments, the section of the probe that hybridizes to the bridging oligonucleotide includes at least 2, at least 3 at least 4, at least 5, or more spatial barcode sequences.

(d) Systems and Kits

[0110] In some embodiments, also provided herein are systems and kits that include one or more reagents to detect one or more analytes described herein. In some instances, the system is used for spatial analysis. In some instances, the system includes a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode. In some instances, the system further includes a plurality of bridging oligonucleotides, wherein a bridging oligonucleotide in the plurality of bridging oligonucleotides comprises (i) a capture-probe-binding sequence and (ii) an analyte-binding sequence. In some instances, the bridging oligonucleotide further comprises (i) a flexible arm, and (ii) an annealing sequence comprising a functional domain, wherein the functional sequence is a primer sequence.

[0111] Also disclosed herein are kits for performing any of the disclosed methods. In some instances, the kits include (a) a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode; (b) a plurality of bridging oligonucleotides, wherein a bridging oligonucleotide in the plurality of bridging oligonucleotides comprises (i) a capture-probe-binding sequence and (ii) an analyte-binding sequence; and (c) instructions for performing the methods disclosed herein.

III. Methods for Copying of Captured Analytes or Analyte Derivatives

(a) Analyte Detection and Reverse Transcribing Captured mRNAs Provided herein are methods for detecting, amplifying, and/or analyzing a biological analyte, e.g., mRNA, to obtain spatial information about the expression of genes in a biological sample (e.g., tissue sample). In some embodiments, disclosed herein are methods of identifying a location of an analyte within a sample. In some embodiments, disclosed herein are methods of amplifying an analyte in a biological sample.

[0112] In some instances, the methods disclosed herein use a bridging oligonucleotide. The

methods provided herein are predicated on the notion that an analyte (or analyte derivative) hybridizes to a capture probe using Watson-Crick hybridization. Thus, provided herein are methods of determining the abundance and location of an analyte, wherein the analyte—or a portion thereof—hybridizes to a capture probe. It is appreciated that other means of connecting to a capture probe could be used, such as ligation. Interactions between analytes and capture probes are disclosed in WO 2020/176788 and U.S. Patent Application Publication No. 2020/0277663, each of which is incorporated by reference in its entirety.

[0113] In some instances, after a capture probe detects (e.g., hybridizes to) an analyte, a plurality of bridging oligonucleotides is provided. In some instances, a bridging oligonucleotide of the plurality hybridizes to a portion of the capture probe. In some instances, the bridging oligonucleotide hybridizes to a portion of the analyte. In some instances, a bridging oligonucleotide of the plurality hybridizes both to a portion of the capture probe and to a portion of the analyte.

[0114] In some embodiments, the methods include contacting the analyte in the biological sample with a substrate. In some instances, a capture probe of the plurality of capture probes hybridizes to an analyte. The bound nucleic acid molecule can then be correlated with a spatial barcode of the capture probe at a distinct spatial position of the substrate. In some embodiments, the nucleic acid molecule (e.g., RNA molecule) in the tissue sample, particularly mRNA is captured on a substrate. In some embodiments, the captured nucleic acid molecule, or a subset thereof, e.g., a portion of the captured nucleic acid molecule, is further analyzed, for example, by sequence analysis.

[0115] In some embodiments, the methods disclosed herein include binding of multiple analytes to the same probe at different target sites on the probe. In some embodiments, the probe includes more than one poly(T) sequence that allows more than one analyte to bind to the probe. (See e.g., FIG. 7)

[0116] In some embodiments, after hybridization of the bridging oligonucleotide, the bridging oligonucleotide is extended using the bound RNA (e.g., mRNA) as a template to obtain a DNA molecule (e.g., DNA, cDNA) using any of the extension methods described herein. In some embodiments, the step of extending the bridging oligonucleotide includes reverse transcription. In some embodiments, the step of extending the bridging oligonucleotide includes sequential ligation.

[0117] In some instances, the methods disclosed herein include reverse transcription. In some instances, reverse transcription includes extension of the bridging oligonucleotides using the analyte as a template. Reverse transcription can be catalyzed by a polymerase (e.g., a DNA polymerase or reverse transcriptase).

[0118] In some embodiments, extending the bridging oligonucleotide includes generating cDNA from the captured (hybridized) RNA. This process involves synthesis of a complementary strand of the hybridized nucleic acid, e.g., generating cDNA based on the captured RNA template (the RNA hybridized to the capture domain of the capture probe). Thus, in an initial step of extending the bridging oligonucleotide, e.g., the cDNA generation, the captured (hybridized) nucleic acid, e.g., RNA, acts as a template for the extension, e.g., reverse transcription, step.

[0119] In some embodiments, the bridging oligonucleotide is extended using reverse transcription. For example, reverse transcription includes synthesizing cDNA (complementary or copy DNA) from RNA, e.g., (messenger RNA), using a reverse transcriptase. In some embodiments, reverse transcription is performed while the tissue is still in place. Reverse transcription includes generating an analyte library, where the analyte library includes the spatial barcodes or a complement thereof from the capture probe. In some embodiments, the bridging oligonucleotide is extended using one or more DNA polymerases.

[0120] In some embodiments, the bridging oligonucleotide includes a primer for producing the complementary strand of the analyte, e.g., a primer for DNA polymerase and/or reverse transcription. The nucleic acid, e.g., DNA and/or cDNA, molecules generated by the extension reaction incorporate the sequence of the capture probe. The extension of the bridging oligonucleotide, e.g., a DNA polymerase and/or reverse transcription reaction, can be performed

using a variety of suitable enzymes and protocols.

[0121] In some embodiments, a full-length DNA, e.g., cDNA, molecule is generated. In some embodiments, a “full-length” DNA molecule refers to the whole of the captured nucleic acid molecule. However, if the nucleic acid, e.g., RNA, was partially degraded in the tissue sample, then the captured nucleic acid molecules will not be the same length as the initial RNA in the tissue sample. In some embodiments, the 3' end of the bridging oligonucleotide, e.g., first strand cDNA molecules, is modified. For example, a linker or adaptor can be ligated to the 3' end of the extended probes. This can be achieved using single stranded ligation enzymes such as T4 RNA ligase or Circligase™ (available from Lucigen, Middleton, WI). In some embodiments, template switching oligonucleotides are used to extend cDNA in order to generate a full-length cDNA (or as close to a full-length cDNA as possible). In some embodiments, a second strand synthesis helper probe (a partially double stranded DNA molecule capable of hybridizing to the 3' end of the extended capture probe), can be ligated to the 3' end of the bridging oligonucleotide, e.g., first strand cDNA, molecule using a double stranded ligation enzyme such as T4 DNA ligase. Other enzymes appropriate for the ligation step are known in the art and include, e.g., Tth DNA ligase, Taq DNA ligase, *Thermococcus* sp. (strain 90N) DNA ligase (9oNTM DNA ligase, New England Biolabs), Ampligase™ (available from Lucigen, Middleton, WI), and SplintR (available from New England Biolabs, Ipswich, MA). In some embodiments, a polynucleotide tail, e.g., a poly(A) tail, is incorporated at the 3' end of the extended probe molecules. In some embodiments, the polynucleotide tail is incorporated using a terminal transferase active enzyme.

[0122] In some embodiments the hybridized bridging oligonucleotide/mRNA analyte/probe product is reverse transcribed. In some embodiments, reverse transcription uses one or more primer sequences from the bridging oligonucleotide. In some embodiments, a 3'OH is used for starting reverse transcription. In some embodiments, reverse transcription is performed while the biological sample is still in place, generating an analyte library, where the analyte library includes the spatial barcodes from the capture probes. The reverse transcription reaction and extension of the capture probe and/or bridging oligonucleotide can be performed using a variety of suitable enzymes and protocols described herein.

[0123] In some embodiments, the hybridized bridging oligonucleotide/mRNA analyte/probe product is amplified using any of the amplification methods described herein. In some embodiments, the reverse transcriptase product is amplified using any of the amplification methods described herein.

[0124] Referring to FIG. 8A, the method herein includes a substrate **801** that has a plurality of capture probes thereon, with a capture probe **802** having a capture domain **803** and **806** and a bridging oligonucleotide complementary sequence **805**, wherein the bridging oligonucleotide complementary sequence **805** includes a spatial barcode. After hybridization of an analyte **808** to the capture domain **803** via e.g. a poly(A) tail **809**, a bridging oligonucleotide comprising a spatial barcode **810** is added to the substrate. In some instances, a plurality of second oligonucleotides is added with the bridging oligonucleotides. In some instances, a second oligonucleotide is a primer sequence **811** that can hybridize to the capture probe.

[0125] The length and sequence of the primer can be designed by one skilled in the art so that it is specific to the capture probe (i.e., so that it does not cross-react with, for example, a sequence of the biological sample's genome). In some embodiments, the primer **811** can include a poly(A) sequence.

[0126] In some instances, addition of the second oligonucleotide (i.e., the primer) results in hybridization of the primer. Extension of the complementary sequence **812** between the primer binding site and the site to which the bridging oligonucleotide has bound can occur. In some instances, extension is performed via polymerization that is catalyzed by a polymerase (e.g., a DNA polymerase or reverse transcriptase). In some instances, after extension, the extended primer and the bridging oligonucleotide are ligated.

[0127] In other instances, oligonucleotides are designed to hybridize to the capture probe after the bridging oligonucleotide hybridizes to the capture probe. Referring to FIG. 8B, the method herein includes a substrate **801** that has a plurality of capture probes thereon, with a capture probe **802** having a capture domain **803** and **806** and a bridging oligonucleotide complementary sequence **805**, wherein the bridging oligonucleotide complementary sequence **805** includes a spatial barcode. In some embodiments, after hybridization of an analyte **808** to the capture domain **803** via e.g., a poly(A) tail **809**, one or more oligonucleotides (e.g., **815**, **816**, and **817**) hybridize to the capture probes. In some instances, the one or more oligonucleotides are barcodes. In some instances, the one or more oligonucleotides are spatial barcodes. In some instances, at least 2, at least 3, at least 4, at least 5, or more oligonucleotides hybridize to the capture probe. The length and sequence of the oligonucleotides can be designed by one skilled in the art so that each is specific to the capture probe (i.e., so that it does not cross-react with a sequence of the biological sample's genome). In some instances, the one or more one or more oligonucleotides hybridize to adjacent sequences of capture probe. In some instances, after hybridization of the oligonucleotides, the one or more oligonucleotides and the bridging oligonucleotide are ligated. In some instances, the one or more oligonucleotides and the bridging oligonucleotide are ligated using any of the ligation methods described herein.

[0128] In some instances, the ligase does not require adenosine triphosphate for ligase activity (e.g., thermostable 5' AppDNA/RNA Ligase, truncated T4 RNA Ligase 2 (trRn12), truncated T4 RNA Ligase 2 K 227Q, truncated T4 RNA Ligase 2 KQ, Chlorella Virus PBCV-1 DNA Ligase, and combinations thereof). See, e.g., Nichols et al., "RNA Ligases," Curr. Protocol. Molec. Biol. 84(1):3.15.1-. 4 (2008); Viollet et al., "T4 RNA Ligase 2 Truncated Active Site Mutants: Improved Tools for RNA Analysis," BMC Biotechnol. 11:72 (2011); and Ho et al., "Bacteriophage T4 RNA Ligase 2 (gp24.1) Exemplifies a Family of RNA Ligases Found in All Phylogenetic Domains," PNAS 99(20):12709-14 (2002), which are hereby incorporated by reference in their entirety for a description of T4 RNA Ligases and truncated T4 RNA Ligases. Thermostable 5' AppDNA/RNA Ligase is an enzyme belonging to the Ligase family that catalyzes the ligation of the 3' end of ssRNA or ssDNA to a 5'-adenylated ssDNA or 5'-adenylated ssRNA. Truncated T4 RNA Ligase 2 is an enzyme belonging to the Ligase family that catalyzes the ligation of dsRNA nicks and ssRNA to ssRNA. It can also ligate the 3' end of RNA or DNA to a 5'-pDNA when annealed to an RNA complement, and the 3' end of RNA to a 5'-pRNA when annealed to a DNA complement, with reduced efficiency. Truncated T4 RNA Ligase 2 K227Q is an enzyme belonging to the Ligase family that catalyzes the ligation of the 3' end of ssRNA to 5' adenylated ssDNA and 5' adenylated ssRNA. It has a reduction of side products as compared to truncated T4 RNA Ligase 2. Truncated T4 RNA Ligase 2 K Q is an enzyme belonging to the Ligase family that catalyzes the ligation of the 3' end of ssRNA to 5' adenylated ssDNA and 5' adenylated ssRNA. It is a preferred choice for ligation of ssRNA to preadenylated adapters and has a reduction of side products as compared to truncated T4 RNA Ligase 2.

[0129] In some embodiments, the T4 RNA Ligase comprises a K 227Q mutation. See Viollet et al., "T4 RNA Ligase 2 Truncated Active Site Mutants: Improved Tools for RNA Analysis," BMC Biotechnol. 11, which is hereby incorporated by reference in its entirety.

[0130] In some instances, cofactors that aid in ligation of the first and second probe are added during ligation. In some instances, the cofactors include magnesium ions (Mg.sup.2+). In some instances, the cofactors include manganese ions (Mn.sup.2+). In some instances, Mg.sup.2+ is added in the form of MgCl.sub.2. In some instances, Mn.sup.2+ is added in the form of MnCl.sub.2. In some instances, the concentration of MgCl.sub.2 is at about 1 mM to about 10 mM. In some instances, the concentration of MnCl.sub.2 is at about 1 mM to about 10 mM.

[0131] In some instances, the ligation occurs at a pH in the range of about 6.5 to about 9.0, about 6.5 to about 8.0, or about 7.5 to about 8.0.

[0132] In some embodiments, the ligation buffer includes an enzyme storage buffer. In some

embodiments, the enzymes storage buffer includes glycerol. In some embodiments, the ligation buffer is supplemented with glycerol. In some embodiments, the glycerol is present in the ligation buffer at a total volume of 15% v/v.

[0133] In situations where a primer or one or more oligonucleotides hybridize to the capture probe, extension of the bridging oligonucleotide occurs as described above in order to create a complementary sequence of the template.

(b) Additional Methods for Spatial Analysis

1. Imaging and Staining

[0134] In some instances, biological samples can be stained using a wide variety of stains and staining techniques. In some instances, the biological sample is a section on a slide (e.g., a 10 μm section). In some instances, the biological sample is dried after placement onto a glass slide. In some instances, the biological sample is dried at 42° C. In some instances, drying occurs for about 1 hour, about 2, hours, about 3 hours, or until the sections become transparent. In some instances, the biological sample can be dried overnight (e.g., in a desiccator at room temperature).

[0135] In some embodiments, a sample can be stained using any number of biological stains, including but not limited to, acridine orange, Bismarck brown, carmine, coomassie blue, cresyl violet, DAPI, eosin, ethidium bromide, acid fuchsine, hematoxylin, Hoechst stains, iodine, methyl green, methylene blue, neutral red, Nile blue, Nile red, osmium tetroxide, propidium iodide, rhodamine, or safranin. In some instances, the methods disclosed herein include imaging the biological sample. In some instances, imaging the sample occurs prior to deaminating the biological sample. In some instances, the sample can be stained using known staining techniques, including Can-Grunwald, Giemsa, hematoxylin and eosin (H&E), Jenner's, Leishman, Masson's trichrome, Papanicolaou, Romanowsky, silver, Sudan, Wright's, and/or Periodic Acid Schiff (PAS) staining techniques. PAS staining is typically performed after formalin or acetone fixation. In some instances, the stain is an H & E stain.

[0136] In some embodiments, the biological sample can be stained using a detectable label (e.g., radioisotopes, fluorophores, chemiluminescent compounds, bioluminescent compounds, and dyes). Detectable labels used to stain biological samples are also described in Section (I)(b)(xvi) of WO 2020/176788 and/or U.S. Patent Application Publication No. 2020/0277663. In some embodiments, a biological sample is stained using only one type of stain or one technique. In some embodiments, staining includes biological staining techniques such as H & E staining. In some embodiments, staining includes identifying analytes using fluorescently-conjugated antibodies. In some embodiments, a biological sample is stained using two or more different types of stains, or two or more different staining techniques. For example, a biological sample can be prepared by staining and imaging using one technique (e.g., H & E staining and brightfield imaging), followed by staining and imaging using another technique (e.g., IHC/IF staining and fluorescence microscopy) for the same biological sample.

[0137] In some embodiments, biological samples can be destained. Methods of destaining a biological sample are known in the art, and generally depend on the nature of the stain(s) applied to the sample. For example, H & E staining can be destained by washing the sample in HCl, or any other acid (e.g., selenic acid, sulfuric acid, hydroiodic acid, benzoic acid, carbonic acid, malic acid, phosphoric acid, oxalic acid, succinic acid, salicylic acid, tartaric acid, sulfurous acid, trichloroacetic acid, hydrobromic acid, hydrochloric acid, nitric acid, orthophosphoric acid, arsenic acid, selenous acid, chromic acid, citric acid, hydrofluoric acid, nitrous acid, isocyanic acid, formic acid, hydrogen selenide, molybdic acid, lactic acid, acetic acid, carbonic acid, hydrogen sulfide, or combinations thereof). In some embodiments, destaining can include 1, 2, 3, 4, 5, or more washes in an acid (e.g., HCl). In some embodiments, destaining can include adding HCl to a downstream solution (e.g., permeabilization solution). In some embodiments, destaining can include dissolving an enzyme used in the disclosed methods (e.g., pepsin) in an acid (e.g., HCl) solution. In some embodiments, after destaining hematoxylin with an acid, other reagents can be added to the

destaining solution to raise the pH for use in other applications. For example, SDS can be added to an acid destaining solution in order to raise the pH as compared to the acid destaining solution alone. As another example, in some embodiments, one or more immunofluorescence stains are applied to the sample via antibody coupling. Such stains can be removed using techniques such as cleavage of disulfide linkages via treatment with a reducing agent and detergent washing, chaotropic salt treatment, treatment with antigen retrieval solution, and treatment with an acidic glycine buffer. Methods for multiplexed staining and destaining are described, for example, in Bolognesi et al., *J. Histochem. Cytochem.* 2017; 65(8): 431-444, Lin et al., *Nat Commun.* 2015; 6:8390, Pirici et al., *J. Histochem. Cytochem.* 2009; 57:567-75, and Glass et al., *J. Histochem. Cytochem.* 2009; 57:899-905, the entire contents of each of which are incorporated herein by reference.

[0138] In some embodiments, immunofluorescence or immunohistochemistry protocols (direct and indirect staining techniques) can be performed as a part of, or in addition to, the exemplary spatial workflows presented herein. For example, tissue sections can be fixed according to methods described herein. The biological sample can be transferred to an array (e.g., capture probe array), wherein analytes (e.g., proteins) are probed using immunofluorescence protocols. For example, the sample can be rehydrated, blocked, and permeabilized (3× SSC, 2% BSA, 0.1% Triton X, 1 U/μl RNA se inhibitor for 10 minutes at 4° C.) before being stained with fluorescent primary antibodies (1:100 in 3× SSC, 2% BSA, 0.1% Triton X, 1 U/μl RNase inhibitor for 30 minutes at 4° C.). The biological sample can be washed, coverslipped (in glycerol+1 U/μl RNA se inhibitor), imaged (e.g., using a confocal microscope or other apparatus capable of fluorescent detection), washed, and processed according to analyte capture or spatial workflows described herein.

[0139] In some instances, a glycerol solution and a cover slip can be added to the sample. In some instances, the glycerol solution can include a counterstain (e.g., DAPI).

[0140] As used herein, an antigen retrieval buffer can improve antibody capture in IF/IHC protocols. An exemplary protocol for antigen retrieval can be preheating the antigen retrieval buffer (e.g., to 95° C.), immersing the biological sample in the heated antigen retrieval buffer for a predetermined time, and then removing the biological sample from the antigen retrieval buffer and washing the biological sample.

[0141] In some embodiments, optimizing permeabilization can be useful for identifying intracellular analytes. Permeabilization optimization can include selection of permeabilization agents, concentration of permeabilization agents, and permeabilization duration. Tissue permeabilization is discussed elsewhere herein.

[0142] In some embodiments, blocking an array and/or a biological sample in preparation of labeling the biological sample decreases nonspecific binding of antibodies to the array and/or biological sample (decreases background). Some embodiments provide for blocking buffers/blocking solutions that can be applied before and/or during application of the label, wherein the blocking buffer can include a blocking agent, and optionally a surfactant and/or a salt solution. In some embodiments, a blocking agent can be bovine serum albumin (BSA), serum, gelatin (e.g., fish gelatin), milk (e.g., non-fat dry milk), casein, polyethylene glycol (PEG), polyvinyl alcohol (PVA), or polyvinylpyrrolidone (PVP), biotin blocking reagent, a peroxidase blocking reagent, levamisole, Carnoy's solution, glycine, lysine, sodium borohydride, pontamine sky blue, Sudan Black, trypan blue, FITC blocking agent, and/or acetic acid. The blocking buffer/blocking solution can be applied to the array and/or biological sample prior to and/or during labeling (e.g., application of fluorophore-conjugated antibodies).

2. Preparation of a Biological Sample for Detection by Capture Probes

[0143] In some instances, the biological sample is deparaffinized. Deparaffinization can be achieved using any method known in the art. For example, in some instances, the biological samples is treated with a series of washes that include xylene and various concentrations of ethanol. In some instances, methods of deparaffinization include treatment of xylene (e.g., three washes at 5

minutes each). In some instances, the methods further include treatment with ethanol (e.g., 100% ethanol, two washes 10 minutes each; 95% ethanol, two washes 10 minutes each; 70% ethanol, two washes 10 minutes each; 50% ethanol, two washes 10 minutes each). In some instances, after ethanol washes, the biological sample can be washed with deionized water (e.g., two washes for 5 minutes each). It is appreciated that one skilled in the art can adjust these methods to optimize deparaffinization.

[0144] In some instances, the biological sample is decrosslinked. In some instances, the biological sample is decrosslinked in a solution containing TE buffer (comprising Tris and EDTA). In some instances, the TE buffer is basic (e.g., at a pH of about 9). In some instances, decrosslinking occurs at about 50° C. to about 80° C. In some instances, decrosslinking occurs at about 70° C. In some instances, decrosslinking occurs for about 1 hour at 70° C. Just prior to decrosslinking, the biological sample can be treated with an acid (e.g., 0.1M HCl for about 1 minute). After the decrosslinking step, the biological sample can be washed (e.g., with 1× PBST).

[0145] In some instances, the methods of preparing a biological sample for probe application include permeabilizing the sample. In some instances, the biological sample is permeabilized using a phosphate buffer. In some instances, the phosphate buffer is PBS (e.g., 1× PBS). In some instances, the phosphate buffer is PB ST (e.g., 1× PBST). In some instances, the permeabilization step is performed multiple times (e.g., 3 times at 5 minutes each).

[0146] In some instances, the methods of preparing a biological sample for probe application include steps of equilibrating and blocking the biological sample. In some instances, equilibrating is performed using a pre-hybridization (pre-Hyb) buffer. In some instances, the pre-Hyb buffer is RNase-free. In some instances, the pre-Hyb buffer contains no bovine serum albumin (BSA), solutions like Denhardt's, or other potentially nuclease-contaminated biological materials.

[0147] In some instances, the equilibrating step is performed multiple times (e.g., 2 times at 5 minutes each; 3 times at 5 minutes each). In some instances, the biological sample is blocked with a blocking buffer. In some instances, the blocking buffer includes a carrier such as tR NA, for example yeast tRNA. In some instances, blocking can be performed for 5, 10, 15, 20, 25, or 30 minutes.

[0148] Any of the foregoing steps can be optimized for performance. For example, one can vary the temperature. In some instances, the pre-hybridization methods are performed at room temperature. In some instances, the pre-hybridization methods are performed at 4° C. (in some instances, varying the timeframes provided herein).

3. Spatial Analysis Methods

[0149] In some embodiments, a method for spatial analysis using the spatial array prepared according to the methods described herein includes capturing an analyte of a biological sample by a capture probe comprising a capture domain and a spatial barcode; and determining a location of the captured analyte in the biological sample based on the spatial barcode in the capture probe. In some instances, the methods of copying the analyte to create an “extended capture probe” include use of a bridging oligonucleotide.

[0150] In some embodiments, the determining step includes amplifying all or part of the analyte specifically bound to the capture domain. In some embodiments, the method includes amplifying all or part of the analyte using isothermal amplification. In some embodiments, the method includes amplifying all or part of the analyte using non-isothermal amplification. In some embodiments, the amplifying creates an amplifying product that includes (i) all or part of sequence of the analyte specifically bound to the capture domain, or a complement thereof, and (ii) all or a part of the sequence of the spatial barcode, or a complement thereof. In some instances, the amplifying step includes methods of copying or amplifying the analyte to create an extended capture probe using the bridging oligonucleotide disclosed herein.

[0151] In some embodiments, the determining step includes sequencing. A non-limiting example of sequencing that can be used to determine the sequence of the analyte and/or spatial barcodes (e.g.,

first and/or second spatial barcode) is in situ sequencing. In some embodiments, in situ sequencing is performed via sequential fluorescence hybridization, sequencing by ligation, nucleic acid hybridization, or high-throughput digital sequencing techniques. In some embodiments, the analyte is RNA or DNA.

[0152] In some embodiments, the analyte is protein. In some embodiments, a method for spatial analysis includes binding of the analyte to an analyte binding moiety. In some embodiments of any of the spatial profiling methods described herein, the analyte binding moiety of the analyte capture agent that binds to a biological analyte can include, but is not limited to, an antibody, or an epitope binding fragment thereof, a cell surface receptor binding molecule, a receptor ligand, a small molecule, a bi-specific antibody, a bi-specific T-cell engager, a T-cell receptor engager, a B-cell receptor engager, a pro-body, an aptamer, a monobody, an affimer, a darpin, and a protein scaffold, or any combination thereof. The analyte binding moiety can bind to the analyte with high affinity and/or with high specificity. The analyte binding moiety can include a nucleotide sequence (e.g., an oligonucleotide), which can correspond to at least a portion or an entirety of the analyte binding moiety. The analyte binding moiety can include a polypeptide and/or an aptamer (e.g., a polypeptide and/or an aptamer that binds to a specific target molecule, e.g., an analyte). The analyte binding moiety can include an antibody or antibody fragment (e.g., an antigen-binding fragment) that binds to a specific analyte (e.g., a polypeptide).

[0153] More particularly, after an analyte has hybridized or otherwise been associated with a capture probe according to any of the methods described above in connection with the general spatial cell-based analytical methodology, the barcoded constructs that result from hybridization/association are analyzed.

[0154] In some embodiments, after contacting a biological sample with a substrate that includes capture probes, a removal step can optionally be performed to remove all or a portion of the biological sample from the substrate. In some embodiments, the removal step includes enzymatic and/or chemical degradation of cells of the biological sample. For example, the removal step can include treating the biological sample with an enzyme (e.g., a proteinase, e.g., proteinase K) to remove at least a portion of the biological sample from the substrate. In some embodiments, the removal step can include ablation of the tissue (e.g., laser ablation).

[0155] In some embodiments, provided herein are methods for spatially detecting an analyte (e.g., detecting the location of an analyte, e.g., a biological analyte) from a biological sample (e.g., present in a biological sample), the method comprising: (a) optionally staining and/or imaging a biological sample on a substrate; (b) permeabilizing (e.g., providing a solution comprising a permeabilization reagent to) the biological sample on the substrate; (c) contacting the biological sample with an array comprising a plurality of capture probes, wherein a capture probe of the plurality captures the biological analyte; and (d) analyzing the captured biological analyte, thereby spatially detecting the biological analyte; wherein the biological sample is fully or partially removed from the substrate.

[0156] In some embodiments, a biological sample is not removed from the substrate. For example, the biological sample is not removed from the substrate prior to releasing a capture probe (e.g., a capture probe bound to an analyte) from the substrate. In some embodiments, such releasing comprises cleavage of the capture probe from the substrate (e.g., via a cleavage domain). In some embodiments, such releasing does not comprise releasing the capture probe from the substrate (e.g., a copy of the capture probe bound to an analyte can be made and the copy can be released from the substrate, e.g., via denaturation). In some embodiments, the biological sample is not removed from the substrate prior to analysis of an analyte bound to a capture probe after it is released from the substrate. In some embodiments, the biological sample remains on the substrate during removal of a capture probe from the substrate and/or analysis of an analyte bound to the capture probe after it is released from the substrate. In some embodiments, the biological sample remains on the substrate during removal (e.g., via denaturation) of a copy of the capture probe (e.g., complement).

In some embodiments, analysis of an analyte bound to a capture probe from the substrate can be performed without subjecting the biological sample to enzymatic and/or chemical degradation of the cells (e.g., permeabilized cells) or ablation of the tissue (e.g., laser ablation).

[0157] In some embodiments, at least a portion of the biological sample is not removed from the substrate. For example, a portion of the biological sample can remain on the substrate prior to releasing a capture probe (e.g., a capture probe bound to an analyte) from the substrate and/or analyzing an analyte bound to a capture probe released from the substrate. In some embodiments, at least a portion of the biological sample is not subjected to enzymatic and/or chemical degradation of the cells (e.g., permeabilized cells) or ablation of the tissue (e.g., laser ablation) prior to analysis of an analyte bound to a capture probe from the substrate.

[0158] In some embodiments, the methods provided herein include spatially detecting an analyte (e.g., detecting the location of an analyte, e.g., a biological analyte) from a biological sample (e.g., present in a biological sample) that include: (a) optionally staining and/or imaging a biological sample on a substrate; (b) permeabilizing (e.g., providing a solution comprising a permeabilization reagent to) the biological sample on the substrate; (c) contacting the biological sample with an array comprising a plurality of capture probes, wherein a capture probe of the plurality captures the biological analyte, wherein the capture probe includes a spatial barcode; (d) contacting the captured biological analyte to a bridging oligonucleotide; (e) extending the bridging oligonucleotide using the analyte as a template to generate an extended capture probe; and (d) analyzing the captured biological analyte and/or the spatial barcode, thereby spatially detecting the biological analyte; where the biological sample is not removed from the substrate.

[0159] In some embodiments, the method further includes subjecting a region of interest in the biological sample to spatial transcriptomic analysis. In some embodiments, one or more of the capture probes includes a capture domain. In some embodiments, one or more of the capture probes comprises a unique molecular identifier (UMI). In some embodiments, one or more of the capture probes comprises a cleavage domain. In some embodiments, the cleavage domain comprises a sequence recognized and cleaved by uracil-DNA glycosylase, apurinic/apyrimidinic (AP) endonuclease (APE1), uracil-specific excision reagent (USER), and/or an endonuclease VIII. In some embodiments, one or more capture probes do not comprise a cleavage domain and is not cleaved from the array.

[0160] In some embodiments, a capture probe can be extended (an “extended capture probe,” e.g., as described herein). For example, extending a capture probe can include generating cDNA from a captured (hybridized) RNA. In some embodiments, the capture probe can be extended to include cDNA from a captured (hybridized) mRNA. This process involves synthesis of a complementary strand of the hybridized nucleic acid, e.g., generating cDNA based on the captured RNA template (the RNA hybridized to the capture domain of the capture probe, e.g., a captured mRNA hybridized to the capture domain). Thus, in an initial step of extending a capture probe, e.g., the cDNA generation, the captured (hybridized) nucleic acid, e.g., mRNA, acts as a template for the extension, e.g., a reverse transcription step.

[0161] In some embodiments, the capture probe is extended using reverse transcription. For example, reverse transcription includes synthesizing cDNA (complementary or copy DNA) from RNA (e.g., mRNA), using a reverse transcriptase. In some embodiments, reverse transcription is performed while the tissue is still in place, generating an analyte library, where the analyte library includes the spatial barcodes from the adjacent proximal capture probes. In some embodiments, the capture probe is extended using one or more DNA polymerases.

[0162] In some embodiments, the capture probe includes a capture domain and a bridging complementary sequence, wherein the bridging oligonucleotide complementary sequence includes a spatial barcode. In some embodiments, a bridging oligonucleotide including a spatial barcode is added to the biological sample or substrate. In some embodiments, a plurality of second oligonucleotides is added with the bridging oligonucleotides. In some embodiments, a second

oligonucleotide can be a primer sequence that can hybridize to the capture probe. In some embodiments, hybridization of the second oligonucleotide (i.e., the primer) to the capture probe results in extension of the bridging oligonucleotide complementary sequence between the primer binding site and the site to which the bridging oligonucleotide has bound can occur. In some instances, extension is performed via polymerization that is catalyzed by a polymerase (e.g., a DNA polymerase or reverse transcriptase). In some instances, after extension, the extended primer and the bridging oligonucleotide are ligated.

[0163] In some embodiments, a capture domain of a capture probe includes a primer nucleic acid sequence for producing a complementary strand of a nucleic acid hybridized to the capture probe, e.g., a primer for DNA polymerase and/or reverse transcription. The nucleic acid, (e.g., DNA and/or cDNA), molecules generated by the extension reaction incorporate the sequence of the capture probe. The extension of the capture probe, e.g., a DNA polymerase and/or reverse transcription reaction, can be performed using a variety of suitable enzymes and protocols.

[0164] In some embodiments, a full-length DNA (e.g., cDNA) molecule is generated. In some embodiments, a “full-length” DNA molecule refers to the whole of the captured nucleic acid molecule. However, if a nucleic acid (e.g., RNA) was partially degraded in the tissue sample, then the captured nucleic acid molecules will not be the same length as the initial RNA in the tissue sample. In some embodiments, the 3' end of the extended probes, e.g., first strand cDNA molecules, is modified. For example, a linker or adaptor can be ligated to the 3' end of the extended probes. This can be achieved using single stranded ligation enzymes such as T4 RNA ligase or Circligase™ (available from Lucigen, Middleton, WI). In some embodiments, template switching oligonucleotides are used to extend cDNA in order to generate a full-length cDNA (or as close to a full-length cDNA as possible). In some embodiments, a second strand synthesis helper probe (a partially double stranded DNA molecule capable of hybridizing to the 3' end of the extended capture probe), can be ligated to the 3' end of the extended probe, e.g., first strand cDNA, molecule using a double stranded ligation enzyme such as T4 DNA ligase. Other enzymes appropriate for the ligation step are known in the art and include, e.g., Tth DNA ligase, Taq DNA ligase, *Thermococcus* sp. (strain 9oN) DNA ligase (9oNTM DNA ligase, New England Biolabs), Ampligase™ (available from Lucigen, Middleton, WI), and SplintR (available from New England Biolabs, Ipswich, MA). In some embodiments, a polynucleotide tail, e.g., a poly(A) tail, is incorporated at the 3' end of the extended probe molecules. In some embodiments, the polynucleotide tail is incorporated using a terminal transferase active enzyme.

[0165] In some embodiments, double-stranded extended capture probes are treated to remove any unextended capture probes prior to amplification and/or analysis, e.g., sequence analysis. This can be achieved by a variety of methods, e.g., using an enzyme to degrade the unextended probes, such as an exonuclease enzyme, or purification columns.

[0166] In some embodiments, extended capture probes are amplified to yield quantities that are sufficient for analysis, e.g., via DNA sequencing. In some embodiments, the first strand of the extended capture probes (e.g., DNA and/or cDNA molecules) acts as a template for the amplification reaction (e.g., a polymerase chain reaction).

[0167] In some embodiments, the amplification reaction incorporates an affinity group onto the extended capture probe (e.g., RNA-cDNA hybrid) using a primer including the affinity group. In some embodiments, the primer includes an affinity group and the extended capture probes includes the affinity group. The affinity group can correspond to any of the affinity groups described previously.

[0168] In some embodiments, the extended capture probes including the affinity group can be coupled to a substrate specific for the affinity group. In some embodiments, the substrate can include an antibody or antibody fragment. In some embodiments, the substrate includes avidin or streptavidin and the affinity group includes biotin. In some embodiments, the substrate includes maltose and the affinity group includes maltose-binding protein. In some embodiments, the

substrate includes maltose-binding protein and the affinity group includes maltose. In some embodiments, amplifying the extended capture probes can function to release the extended probes from the surface of the substrate, insofar as copies of the extended probes are not immobilized on the substrate.

[0169] In some embodiments, the extended capture probe or complement or amplicon thereof is released. The step of releasing the extended capture probe or complement or amplicon thereof from the surface of the substrate can be achieved in a number of ways. In some embodiments, an extended capture probe or a complement thereof is released from the array by nucleic acid cleavage and/or by denaturation (e.g., by heating to denature a double-stranded molecule).

[0170] In some embodiments, the extended capture probe or complement or amplicon thereof is released from the surface of the substrate (e.g., array) by physical means. For example, where the extended capture probe is indirectly immobilized on the array substrate, e.g., via hybridization to a surface probe, it can be sufficient to disrupt the interaction between the extended capture probe and the surface probe. Methods for disrupting the interaction between nucleic acid molecules include denaturing double stranded nucleic acid molecules are known in the art. A straightforward method for releasing the DNA molecules (i.e., of stripping the array of extended probes) is to use a solution that interferes with the hydrogen bonds of the double stranded molecules. In some embodiments, the extended capture probe is released by an applying heated solution, such as water or buffer, of at least 85° C., e.g., at least 90, 91, 92, 93, 94, 95, 96, 97, 98, or 99° C. In some embodiments, a solution including salts, surfactants, etc. that can further destabilize the interaction between the nucleic acid molecules is added to release the extended capture probe from the substrate.

[0171] In some embodiments, where the extended capture probe includes a cleavage domain, the extended capture probe is released from the surface of the substrate by cleavage. For example, the cleavage domain of the extended capture probe can be cleaved by any of the methods described herein. In some embodiments, the extended capture probe is released from the surface of the substrate, e.g., via cleavage of a cleavage domain in the extended capture probe, prior to the step of amplifying the extended capture probe.

[0172] In some embodiments, probes complementary to the extended capture probe can be contacted with the substrate. In some embodiments, the biological sample can be in contact with the substrate when the probes are contacted with the substrate. In some embodiments, the biological sample can be removed from the substrate prior to contacting the substrate with probes. In some embodiments, the probes can be labeled with a detectable label (e.g., any of the detectable labels described herein). In some embodiments, probes that do not specially bind (e.g., hybridize) to an extended capture probe can be washed away. In some embodiments, probes complementary to the extended capture probe can be detected on the substrate (e.g., imaging, any of the detection methods described herein).

[0173] In some embodiments, probes complementary to an extended capture probe can be about 4 nucleotides to about 100 nucleotides long. In some embodiments, probes (e.g., detectable probes) complementary to an extended capture probe can be about 10 nucleotides to about 90 nucleotides long. In some embodiments, probes (e.g., detectable probes) complementary to an extended capture probe can be about 20 nucleotides to about 80 nucleotides long. In some embodiments, probes (e.g., detectable probes) complementary to an extended capture probe can be about 30 nucleotides to about 60 nucleotides long. In some embodiments, probes (e.g., detectable probes) complementary to an extended capture probe can be about 40 nucleotides to about 50 nucleotides long. In some embodiments, probes (e.g., detectable probes) complementary to an extended capture probe can be about 5, about 6, about 7, about 8, about 9, about 10, about 11, about 12, about 13, about 14, about 15, about 16, about 17, about 18, about 19, about 20, about 21, about 22, about 23, about 24, about 25, about 26, about 27, about 28, about 29, about 30, about 31, about 32, about 33, about 34, about 35, about 36, about 37, about 38, about 39, about 40, about 41, about 42, about 43, about 44, about 45, about 46, about 47, about 48, about 49, about 50, about 51, about 52, about 53,

about 54, about 55, about 56, about 57, about 58, about 59, about 60, about 61, about 62, about 63, about 64, about 65, about 66, about 67, about 68, about 69, about 70, about 71, about 72, about 73, about 74, about 75, about 76, about 77, about 78, about 79, about 80, about 81, about 82, about 83, about 84, about 85, about 86, about 87, about 88, about 89, about 90, about 91, about 92, about 93, about 94, about 95, about 96, about 97, about 98, and about 99 nucleotides long.

[0174] In some embodiments, about 1 to about 100 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 1 to about 10 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 10 to about 100 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 20 to about 90 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 30 to about 80 probes (e.g., detectable probes) can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 40 to about 70 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 50 to about 60 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe. In some embodiments, about 2, about 3, about 4, about 5, about 6, about 7, about 8, about 9, about 10, about 11, about 12, about 13, about 14, about 15, about 16, about 17, about 18, about 19, about 20, about 21, about 22, about 23, about 24, about 25, about 26, about 27, about 28, about 29, about 30, about 31, about 32, about 33, about 34, about 35, about 36, about 37, about 38, about 39, about 40, about 41, about 42, about 43, about 44, about 45, about 46, about 47, about 48, about 49, about 50, about 51, about 52, about 53, about 54, about 55, about 56, about 57, about 58, about 59, about 60, about 61, about 62, about 63, about 64, about 65, about 66, about 67, about 68, about 69, about 70, about 71, about 72, about 73, about 74, about 75, about 76, about 77, about 78, about 79, about 80, about 81, about 82, about 83, about 84, about 85, about 86, about 87, about 88, about 89, about 90, about 91, about 92, about 93, about 94, about 95, about 96, about 97, about 98, and about 99 probes can be contacted to the substrate and specifically bind (e.g., hybridize) to an extended capture probe.

[0175] In some embodiments, the probes can be complementary to a single analyte (e.g., a single gene). In some embodiments, the probes can be complementary to one or more analytes (e.g., analytes in a family of genes). In some embodiments, the probes (e.g., detectable probes) can be for a panel of genes associated with a disease (e.g., cancer, Alzheimer's disease, Parkinson's disease).

[0176] In some instances, the capture probe can be amplified or copied, creating a plurality of cDNA molecules. In some embodiments, cDNA can be denatured from the capture probe template and transferred (e.g., to a clean tube or microwell plate) for amplification, and/or library construction. The spatially-barcoded cDNA can be amplified via PCR prior to library construction. The cDNA can then be enzymatically fragmented and size-selected in order to optimize for cDNA amplicon size. P5 and P7 sequences directed to capturing the amplicons on a sequencing flowcell (e.g., Illumina sequencing instruments) can be appended to the amplicons, i7, and i5 can be used as sample indexes, and TruSeq Read 2 can be added via End Repair, A-tailing, Adaptor Ligation, and PCR. The cDNA fragments can then be sequenced using paired-end sequencing using TruSeq Read 1 and TruSeq Read 2 as sequencing primer sites. A skilled artisan will understand that additional or alternative sequences used by other sequencing instruments or technologies are also equally applicable for use in the aforementioned methods as the current methods are not limited to any a particular sequencing platform.

[0177] In some embodiments, where a sample is barcoded directly via hybridization with capture probes or analyte capture agents hybridized, bound, or associated with either the cell surface, or introduced into the cell, as described above, sequencing can be performed on the intact sample.

[0178] A wide variety of different sequencing methods can be used to analyze the barcoded analyte or moiety. In general, sequenced polynucleotides can be, for example, nucleic acid molecules such

as deoxyribonucleic acid (DNA) or ribonucleic acid (RNA), including variants or derivatives thereof (e.g., single stranded DNA or DNA/RNA hybrids, and nucleic acid molecules with a nucleotide analog).

[0179] Sequencing of polynucleotides can be performed by various systems. More generally, sequencing can be performed using nucleic acid amplification, polymerase chain reaction (PCR) (e.g., digital PCR and droplet digital PCR (ddPCR), quantitative PCR, real time PCR, multiplex PCR, PCR-based single plex methods, emulsion PCR), and/or isothermal amplification. Non-limiting examples of methods for sequencing genetic material include, but are not limited to, DNA hybridization methods (e.g., Southern blotting), restriction enzyme digestion methods, Sanger sequencing methods, next-generation sequencing methods (e.g., single-molecule real-time sequencing, nanopore sequencing, sequence by synthesis sequencing and Polony sequencing), ligation methods, and microarray methods.

EXAMPLES

Example 1

Methods for Reverse Transcribing One or More mRNA Analytes from a Biological Sample

[0180] In a non-limiting example, a capture probe is immobilized on a capture probe array. FIG. 7 shows an exemplary illustration of a capture probe interacting with an mRNA of a biological sample on a capture probe array. For example, a method of identifying a location of an mRNA in a biological sample can include: (a) contacting the biological sample with a substrate, as described herein; (b) hybridizing the capture probe to the target analyte mRNA, generating a captured mRNA; (c) contacting the captured mRNA to a bridging oligonucleotide, creating a hybridized product; (d) extending the bridging oligonucleotide by reverse transcription; (e) amplifying the hybridized product; and determining all or a part of the sequence of the captured mRNA and the spatial barcode of the capture probe to identify the location of the mRNA in the biological sample.

[0181] Referring to FIG. 7, an array includes a plurality of probes. A probe is attached to the surface of the array at one end (e.g., 5' end). The probe includes sequences complementary to an analyte sequence. For example, the sequence complementary to an analyte sequence is a poly(T) sequence (**703** and **706**). A biological sample that includes an mRNA analyte is added to the array. The mRNA analyte hybridizes to a capture probe (**708** and **710**). After hybridization, a bridging oligonucleotide is added to the biological sample (**714**). The bridging oligonucleotide includes a random hexamer sequence (or a VNN sequence (e.g., complementary to **704** and **707**), a flexible arm, and a sequence specific to the spatial barcode of the capture probe. The bridging oligonucleotide hybridizes to the mRNA analyte and the capture probe. After hybridization of the bridging oligonucleotide, the bridging oligonucleotide is extended.

[0182] Referring to FIGS. **8A-8B**, the sequence specific to the spatial barcode of the capture probe in the bridging oligonucleotide binds to one or more complementary regions of the spatial barcode region (black circles) of the probe. As seen in FIG. **8A**, there can be one spatial barcode region or more than one (FIG. **8B**). After hybridization of the bridging oligonucleotide to the mRNA analyte and to the probe, the bridging oligonucleotide can be further extended. After hybridization and extension, the product can be amplified, a sequencing library generated, and the sequence of the spatial barcode and the target mRNA analyte determined and spatially located on the spatial array as previously described.

Claims

1. (canceled)
2. A composition comprising: (a) a substrate comprising a plurality of capture probes, wherein a capture probe in the plurality of capture probes comprises a capture domain and a spatial barcode; and (b) a plurality of bridging oligonucleotides, wherein a bridging oligonucleotide in the plurality of bridging oligonucleotides comprises (i) an analyte-binding sequence, and (ii) a sequence

comprising a primer sequence.

3. The composition of claim 2, wherein the capture probe comprises one or more additional capture domains.
 4. The composition of claim 2, wherein the capture probe comprises at least two to at least five capture domains.
 5. The composition of claim 2, wherein the bridging oligonucleotide further comprises a flexible arm sequence.
 6. The composition of claim 5, wherein the flexible arm or the primer sequence comprises a poly(T) sequence or a poly(A) sequence.
 7. The composition of claim 5, wherein the flexible arm sequence comprises a chemical group selected from a hydroxyl group, an amine group, a functional amine group, or a chemically modified amine group.
 8. The composition of claim 2, wherein the bridging oligonucleotide is about 40 nucleotides to about 140 nucleotides in length.
 9. The composition of claim 2, wherein the bridging oligonucleotide further comprises a capture-probe-binding sequence.
 10. The composition of claim 2, wherein the capture-probe-binding sequence comprises a sequence that is complementary to the spatial barcode.
 11. The composition of claim 2, wherein the bridging oligonucleotide comprises a 3'-OH end.
 12. The composition of claim 2, further comprising a biological sample placed on the substrate.
 13. The composition of claim 12, wherein the biological sample is a tissue section.
 14. The composition of claim 12, wherein the biological sample is a formalin-fixed, paraffin-embedded (FFPE) tissue sample, a frozen tissue sample, or a fresh tissue sample.
 15. The composition of claim 12, further comprising a polymerase or a reverse transcriptase.
 16. The composition of claim 12, wherein the biological sample is stained using hematoxylin, eosin, immunohistochemistry, or immunofluorescence.
 17. The composition of claim 2, wherein the analyte-binding sequence is complementary to a DNA molecule.
 18. The composition of claim 2, wherein the analyte-binding sequence is complementary to an RNA molecule.
 19. The composition of claim 2, wherein the capture domain comprises a poly(T) sequence.
 20. The composition of claim 2, wherein the substrate comprises a plurality of beads, wherein a bead of the plurality is attached to the capture probe.
 21. The composition of claim 2, wherein the capture probe is affixed to the substrate at its 5' end.
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