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Bar Codes All The Way Down

We *can* track anything; policy will determine what we *do* track.

Inside:

Bar codes must be good for business productivity because they're everywhere. Witness any magazine, Cheerios box, or candy bar. Printed bar codes work for lots of stuff, and there's lots of stuff they don't work for. They work well on packages, but they don't work on flexible things like clothing or on things that don't have smooth surfaces: fly swatters and footballs.

The reason to tag items has been for local inventory management. To answer the questions, "What's in this warehouse?" or "What's in this store?" The Internet enables a network between the tag reader and the computer for answers to more interesting, *supply-chain* questions: "Where did it go?" and "How did it go?" and "What's in the closest warehouse?" For this, new ways of tagging are here to ensure that everything, from pallets to individual pills, goes where it's supposed to, efficiently. In the future, things as small as individual molecules will be tagged and tracked. We'll have the technical means to physically track *anything*. Policy—what we allow—will determine what we *do* track.

Everyone who has bought anything in the last twenty years knows bar codes. A laser beam from a handheld device or from behind a glass plate on the counter reads the bar code. The bar code doesn't have the price—that's in a database in the store's back room—the bar code just identifies the item. Bar codes work for coupons too. The coupon is coded as a coupon for a particular product or family of products. The computer in the back room matches your purchases with the coupons; the computer knows how much the coupon is worth, whether it is current, and whether it applies to the product you bought. If it all correlates, you get the discount.

11-05-2003

But optical bar codes have problems. How many times have you watched the checker repeatedly swipe the article across the glass, get frustrated, and type in the Universal Product Code (UPC)? You spent an hour loading the cart, and now each item has to come out to have its bar code rotated into position over the reader. Just where is the bar code on that fifty-pound bag of dog food?

Did the store give you the sale price? To do that, someone had to update the prices in the store's database. All you can do is check the printed receipt for the right price. Stores sometimes "forget."

As Wal-Mart (**WMT**) and others found, bar codes can be a two-way street. Thieves armed with self-sticking bar code labels (for a now-defunct training site, see www.re-code.com/screengrab1_highres.jpg) relabel expensive items as something cheaper. Neither the bar-code reader nor the checker matches the physical item with its coded label; the VCR gets charged as a box of soap.

RFID

Bar codes don't work well in harsh environments (dusty, muddy, wet, rough handling) that damage or obscure the tag, and they don't work well in environments, such as package or baggage handling, where the item's uncontrolled orientation defeats the optical reader. Electromagnetic tagging, called radio-frequency identification (RFID), works well in these situations.

Like bar-code systems, RFID systems use a reader and tags, but use radio frequencies instead of light for identification. Unlike optical bar-code systems, RFID systems don't need line of sight. They can be inside a package or be behind an opaque, protective layer.

Optical systems require a human between the data and the computer to aim the reader or to position the UPC label over a glass window. In RFID systems, the computer collects the information without human assistance. RFID systems can read everything in a shopping cart in the time it takes to push the cart past the reader. So why aren't RFID systems everywhere?

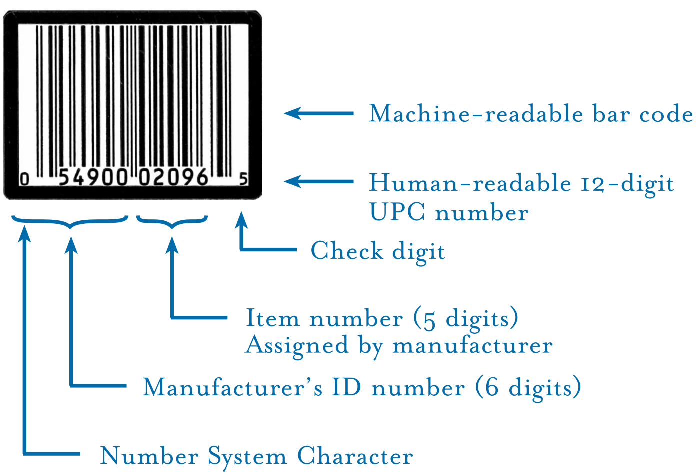
Two problems hold back RFID systems: standards and cost. Optical bar-code systems have overcome both problems.

Bar-code standards (see fig. 1) have been in place for thirty years. Standards are important because universal codes mean universal readers. Instead of custom systems, there's a much larger market for standard readers, which drives down costs. Also, standards are designed to extend the application environment from local to global.

But standards are on the way for RFID (see fig. 2). MIT's Auto-ID Center (www.autoidcenter.org) is creating an Internet-based system to automatically identify RFID-tagged items anywhere. Having defined an Electronic Product Code (EPC), RF communications protocols, data management structure, RFID readers, and RFID tags, MIT and its partners, which include Gillette (**G**), Proctor & Gamble (**PG**), Sun Microsystems (**SUNW**), Unilever (**UN**), and Wal-Mart, have begun field trials.

Cost is still a problem. Bar codes cost almost nothing to print. Today's cheapest RFID tags cost twenty to thirty cents. The most expensive can cost $150.

Universal Product Code (UPC)



0 Standard UPC number
1 Reserved
2 Random-weight units (fruits, vegetables)
3 Pharmaceuticals
4 In-store marking for retailers
5 Coupons
6 Standard UPC number
7 Standard UPC number
8 Reserved
9 Reserved

Fig. 1. Universal Product Codes from a 30-can carton of Dr. Pepper. UPCs are managed by the Uniform Code Council.

Today, UPCs label almost everything. The left half of the number identifies the manufacturer; the right half, assigned by the manufacturer, identifies the type of item.

My office refrigerator is filled with Dr. Pepper. Dr. Pepper's manufacturer, 054900, is The Pepsi Bottling Group, Inc. The UPC on the cardboard carton of Dr. Pepper cans is 0 54900 02096 5. An individual 12-oz can from the carton uses a code of 0 783150 4 (shorthand for 0 78000 00315 4, suppressing zeroes to fit the code on a small item). The six-pack of 16-oz plastic bottles is 0 54900 02037 8. You can translate these and other UPCs at www.upcdatabase.com, which is a database maintained by its users (I entered the description of the 30-can carton; the other examples were already there.)

The *can's* UPC identifies it as a 12-oz can of Dr. Pepper. The *carton's* number identifies it as a carton of thirty 12-oz cans. A *pallet* of cartons also has a unique UPC item number. Each such *level* of packaging carries its own item number, but there's no way to identify *individual* items. Cans carry the same number as other cans. Cartons carry the same number as other cartons. Pallets carry the same number as other pallets.

The PDF417 (used by FedEx), Data Matrix, and MaxiCode (used by UPS) standards extend UPC's "1D" linear-strip, optical bar codes to a 2D format. The 2D formats are used where there's a requirement for more information or where label space is restricted. (Data Matrix is, for example, thirty times more compact than some 1D bar codes.) These 2D optical bar

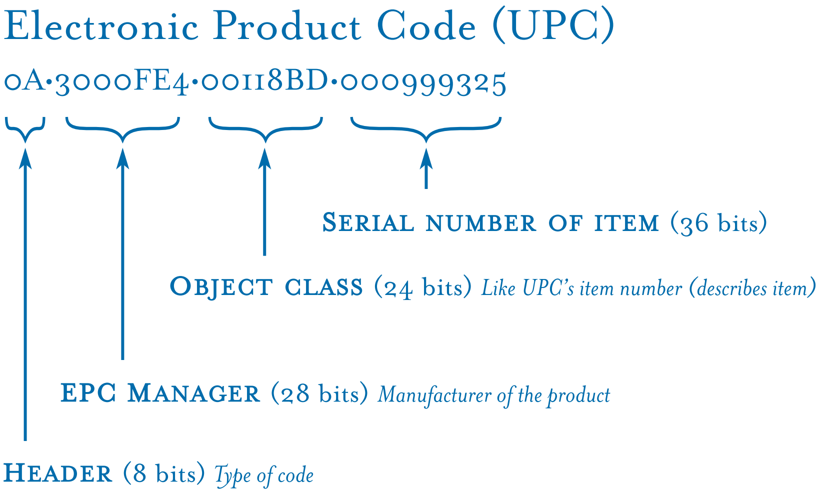


Fig. 2. The Auto-ID Center's Electronic Product Code gives each item a unique identifying number.

codes retain the low-cost advantage of 1D bar codes, they can be printed on, stamped into, or molded into items at manufacture, or added later at almost no cost. They retain the disadvantage of having an expensive, error-prone human to position the tag for the reader. A further disadvantage is that reading 2D optical bar codes is substantially more difficult than reading 1D bar codes. Reading 2D bar codes requires better orientation, steadiness, and new procedures from human operators. It is particularly challenging to read 2D bar codes on moving packages (the foremost application of 2D bar codes).

The Auto-ID Center's standard for RFID carries labeling one step further. In addition to a manufacturer number and an item identifier, the Electronic Product Code can assign a unique number to *every end item.* Each pallet has a unique number that differs from all other pallets, each carton has a unique number, and each 12-oz can of Dr. Pepper has a unique number. With EPC, it's possible to distinguish one can from another and one carton from another. What's the value of that? Supply-chain visibility: seeing where it goes, how fast it goes there, and how it goes there.

My cans of Dr. Pepper moved from the manufacturer to my refrigerator through the "supply chain." One of the biggest problems in the supply chain, euphemistically called "shrinkage," is loss or theft. Supply-chain shrinkage costs retailers more than $30 billion a year.

In moving pallets of UPC-labeled Dr. Pepper cartons through the supply chain, one pallet looks like any other. The bar-code reader can tell that it's a pallet of Dr. Pepper, but it can't tell anything about its origin, where it's been, or where it should be going. That may not be critical for a pallet of Dr. Pepper worth a few hundred dollars, but what about a pallet of single-malt scotch, of prescription drugs, or of MP-3 players? It's easier for high-value items to get lost and to show up for sale somewhere else. Wherever they show up, there's no hint of whence they came.

RFID gives each pallet, case, and bottle of scotch a

Other RFID Tags

We've talked only about the cheapest RFID tags for the Electronic Product Code (EPC) because they address the largest and most important market. But EPC tags are simple transponders—with a chip the size of a grain of sand, an antenna, and enough packaging to connect and to protect the pieces. The reader sends out an electromagnetic query. The RFID transponder collects enough energy from the query signal (in about one-twentieth of a second) to power its circuits and to respond with its unique EPC.

More expensive RFID tags might have batteries and read/write memory. An RFID tag with its own battery transmits farther than one powered by the incoming signal.

RFID tags with read/write memory label reusable containers. The tags on shipping containers are programmed with information about the shipper, route, destination, and contents.

RFID tags are the core of the 5-million throughway toll transponders that let drivers roll through toll booths without stopping. They are also inside the key sets of expensive cars. The car starts only if the key fits and the car recognizes the key's ID.

Early automotive RFID tags just broadcast an ID, but that could be intercepted and duplicated. Newer tags build in security. One way uses a random number generator, a cryptographic algorithm, and a secret number ("private key") that's inside the reader and inside the RFID tag. The reader transmits a random number of, say, forty bits. The reader and the RFID chip each use the private key and the random number to compute a 24-bit number. The RFID tag returns this 24-bit number for the reader to check against its result. If the numbers match, the engine starts.

unique identifier. RFID readers catalog the pallet as it comes into the warehouse from the loading dock. From the pallet's number, database entries tell when and where it was manufactured, when it left the factory, where it has been, and where it should be going. If the pallet gets lost, the database can show where (between which points) and when. This makes it difficult for a pallet of valuable items to surface anonymously. Any pallet, case, or bottle passing a reader will be immediately identified. It's more difficult to lose a pallet or to load it on a truck bound for the wrong destination.

At the retail end of the supply chain, the biggest problem for manufacturers is empty shelves. If a manufacturer's product is not on the shelf, customers leave the store or they buy a competitor's product. With cheap readers and with RFID tags on individual items, "smart shelves" could alert the store's restockers when shelves run low. These systems could also track expiration dates for each item, reducing prices on soon-to-expire packages.

It sounds great, but there's still the problem of expensive tags and expensive readers. Today's cheapest tags cost about twenty cents in million-unit quantities. To be cost effective for Dr. Pepper cans, RFID tags need to get below a nickel. Readers, which today cost $1,000, need to get to $100.

Readers will get cheaper as the EPC standard spreads. The Auto-ID Center already has a reference design for a $100 reader.

More than a hundred companies, including Motorola (**MOT**), Philips Semiconductors, Siemens (**SI**), and Texas Instruments (**TXN**), make RFID tags, so there's plenty of competition working toward five-cent tags. Some of these companies, such as Escort Memory Systems, Savi Technologies, and TransCore, concentrate on the high end of the market. In 2002, manufacturers shipped about 220-million RFID tags. The Allied Business Alliance estimates that RFID shipments will grow to 1.6 billion tags by 2007. Almost half of these will be in supply-chain applications. Sales of RFID systems, which were $1.4 billion in 2002, should double by 2005.

The large integrated device manufacturers, that build RFID tags with conventional chips and with conventional antennas, will have difficulty getting to a nickel. The chip and the antenna each cost that much, and so does the packaging.

Startup Alien Technology, which signed a contract in January 2003 to deliver 500-million RFID tags to Gillette, has a better idea. Alien begins with smaller chips. Instead of using a diamond saw to cut wafers into chips that are large enough for today's automatic packaging handlers to manipulate, Alien uses etching (the same process that builds circuits on the wafer) to chop each wafer into 250,000 grain-of-sand-sized, specially shaped chips. In a process called fluidic self-assembly, chips suspended in liquid flow over a surface studded with indentations that precisely complement the tiny chips' unique shape. The fluid-borne chips fall reliably into and self-align in the indentations. This self-assembly process, pioneered by Alien Technology, by the University of California, Berkeley, and by MicroAssembly Technologies (also a startup), assembles tens of thousands of devices in a single step.

With good prospects for low-cost chips and for low-cost assembly, that leaves the antenna. Conventional methods produce antennas for five to fifteen cents. Here, Rafsec has ideas (www.rafsec.com). Rafsec stamps metal on top of conductive-ink printing to make antennas in bulk for about one cent.

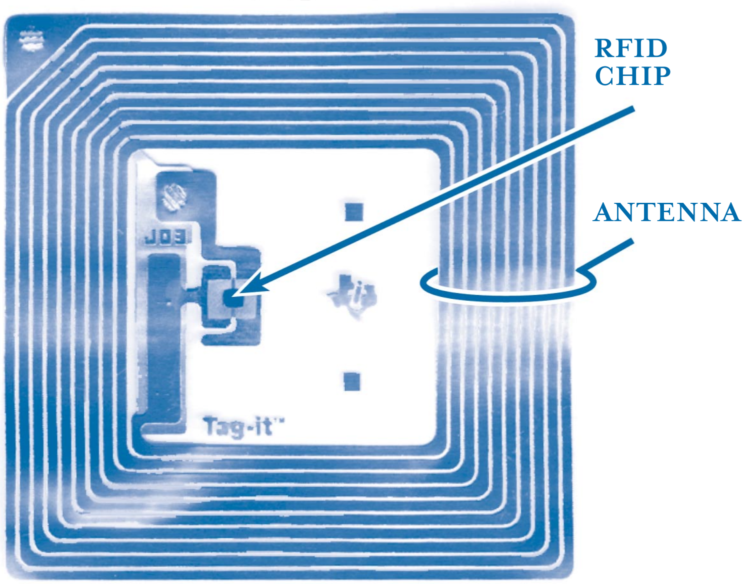


Fig. 3. An RFID tag from Texas Instruments is a tiny chip (left center) surrounded by windings of a copper antenna. (Courtesy of Texas Instruments.)

Alien and Rafsec are just two examples of many promising ways the cost goal might be reached.

RFID looks ready to take off and to revolutionize the supply chain, but a new hurdle appears: acceptance.

Consumer-privacy advocates fear that individuals would be tracked through a store's access to tags on items the individual owns. Walk into a clothing store and the store's computers know by reading the tags on your clothing what you are likely to look at and how much you are likely to spend.

So there's a tradeoff: how much privacy do you want and how much do you want RFID's advantages? Do you want your washing machine to adjust its wash based on what its reader sees inside? Do you want the tag as a receipt and proof of purchase or do you want anonymity? Since consumers fall on both sides of these questions, RFID tags will be equipped with a "kill" feature, which allows the store or the customer to nullify the chip's response.

Fig. 4. IntelliDOT uses cheap printing and optical readers, but carries as much information as an Electronic Product Code. (Courtesy of intelliDOT.)

If you are a pack rat like I am, there comes a time when you can no longer locate something. RFID may come to our aid. Your home's tag readers will be able to find anything with a tag on it.

RFID will proliferate because the standards are gaining acceptance and because RFID tags are already cost-effective for applications at the top of the supply chain, such as shipping containers and pallets. Success in these applications pays for development even as increasing volumes reduce costs. This should sound familiar because it is the same story as the high-margin PC microprocessors that paid the process-development costs for embedded microprocessors. As costs decline, RFID applications will migrate from pallets to cases, and then to individual items.

The RFID tag on an individual item can be its receipt, its warranty certificate, and its proof of ownership. When you return an item, the store's computers will know whether it is the same item you bought, when you bought it, and whether it was on sale.

Two things distinguish UPCs from EPCs. First, UPCs are optical and generally require a human in the loop, while EPCs work via radio frequencies and don't require a human in the loop. Second, UPCs identify only the manufacturer and type of item, while EPCs can identify each item individually.

IntelliDOT

Is there any need for bar codes below the level of packages on a store shelf? A good example is prescription drugs. Getting the right medications to the right patients at the right time and with the correct dose is expensive and it is error prone. Bar codes on pills could help, but UPCs don't carry enough information and RFID tags are too big and too expensive to label individual pills (and tags may not be OK to swallow).

Startup intelliDOT (www.intelliDOT.net) has a solution. IntelliDOT puts a special pattern on each pill. It's as cheap to produce as a conventional UPC, but it carries as much information as an EPC. Each pill can have its own number. The pill's code can be used in the same way as an EPC, to identify the manufacturer, to track its expiration date, and to connect doses to individual patients.

Quantum dots

Quantum dots take bar codes to the atomic level.

Start with a chunk of semiconductor material. Cut it in half. Cut the half in half. Keep doing this. How many times would you have to cut it in half before the material changed color? If you think it won't change color, you'll be surprised. Once you get to a quantum dot, it'll be a different color. Here's how. The quantum dot gets its name from its "quantum-mechanical" properties and from its geometry—quantum dots behave like zero-dimensional objects (points or dots). Quantum mechanics is the name for the unique behavior of individual atoms or parts of atoms.

If the electrons have little energy, they stick close to the atoms—they are in the "low-energy band." If we pump energy into the semiconductor (by shining a laser at it or by applying a voltage), the electrons absorb the energy. This excites them and makes them move farther away from their atoms, to the "high-energy band."

Constantly slicing the material in half eventually encroaches on the electrons' physical space. When the chunk gets small enough (~6 nm), the electrons don't have enough room to move around; this is called "quantum confinement." The chunk has only a few hundred to a few thousand atoms.

Shining a laser on the material always energizes its electrons up to the high-energy band, and sooner or later the electrons always fall back to the low-energy band. As they fall back, they release light at various wavelengths. When the electrons are quantum-confined, however, an interesting thing happens. The electrons give up their energy by releasing light at a *precise* wavelength. In one case, the energy difference between the low-energy band and the high-energy band corresponds to red light. The low-energy electrons can absorb any photon more energetic than red light to move to the high-energy band, but when they fall from the high-energy band to the low-energy band, they emit only red photons. *And we can tune this behavior*: if the chunk is a little smaller (~2 nm), the electrons emit only

Slicing Semiconductors to Dots

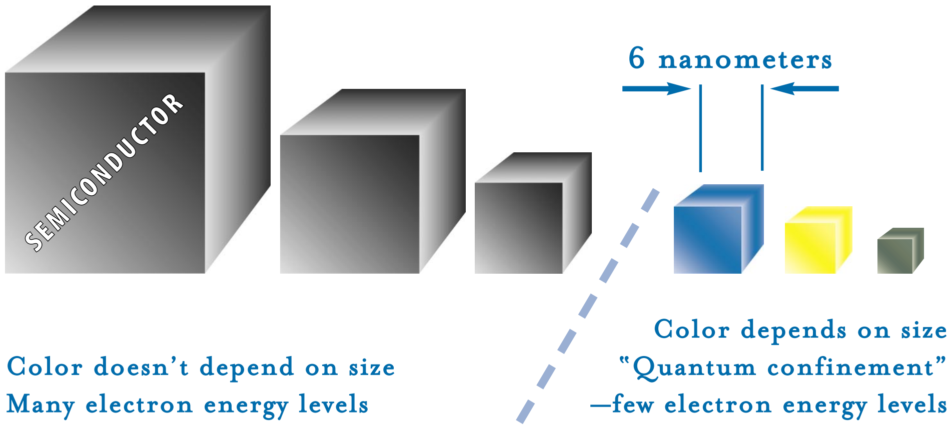


Fig. 5. Slice a semiconductor into smaller and smaller chunks and eventually it changes color! Size does matter.

blue photons. Quantum dots are one to two times the diameter of a DNA molecule.

The dots by themselves aren't good for much. In a normal-size chunk of material there are almost no surface atoms compared to the number of atoms in the volume's interior, so the material's properties are governed by the interior atoms. As the volume gets smaller, the ratio of surface atoms to interior atoms rises until, at the volumes of quantum dots, the surface atoms determine the material's properties. Since surface atoms aren't bound into the same stable positions as atoms in the volume's interior, they are susceptible to contaminants and will react readily. For this reason, quantum dots need a protective shell. A polymer coating enables controlled chemical bonds to biological molecules. The combination becomes a "marker" in biological experiments (see fig. 6). Markers, which attach to otherwise elusive molecules, have fluorescent, magnetic, or other properties that experimenters can track with laboratory equipment.

Today's biological markers are fluorescent dyes; these

Other Quantum-Dot Applications

Startup Zia Laser, Inc. (www.zialaser.com) makes quantum-dot-based *lasers* for telecommunications applications. Today's industry-standard, "quantum-well distributed-feedback" (QW DFB) lasers for fiber optic line-driver applications are temperature sensitive, necessitating elaborate compensation measures. "*Quantum dot* distributed-feedback" (QD DFB) lasers, thanks to quantum confinement, produce a sharp spectral output and are five times less sensitive to temperature than quantum-well lasers. Zia Laser offers an uncooled, 5-mW QD DFB laser at 1310 nm with five times the stability of the equivalent QW DFB laser. Zia also makes 1550-nm QD DFB lasers with output power of up to 40 mW for longer-range communication. *Quantum-dot-based lasers and amplifiers will displace today's industry-standard components in optical networks.*

Difficult-to-copy bar codes (unique spectral signature) built of quantum dots can be embedded in textiles or other materials for authentication of manufactured goods. Similar quantum-dot bar codes can be embedded in currency papers and in valuable documents to make forgery more expensive and more difficult.

Quantum dots may revolutionize computer displays and computers too. For displays, the size of the dot determines the wavelength of emitted light, and quantum dots are small. It should be possible to construct dense, efficient displays with active red, green, and blue quantum-dot pixels. Quantum dots promise computers built out of single-electron devices. This means computers with much denser circuits and with lower power consumption than today's computers. But computer applications are on the distant horizon compared to the use of quantum dots in biological and optical applications.

When quantum dots are cheap enough, they'll do wonders for paints and pigments. Instead of absorbing sunlight and *reflecting* only red, your car's paint will absorb sunlight and *emit* red.

dyes have several disadvantages. They don't emit much light relative to the amount of source illumination. They fade rapidly, limiting the time to do experiments. Their fluorescent signatures spread fairly broadly across the spectrum. This makes it difficult to do experiments with several markers because their spectral signatures overlap. Fluorescent dyes need incoming (source) illumination that is close to the dyes' emission frequencies; this requires filters. And multiple-dye experiments require multiple illumination sources.

Quantum dots suffer none of these shortcomings. Each biological unknown can be tagged with a uniquely colored dot. The dots have a very narrow emission range, so many unknowns can be tested in a single experiment. All the dots respond to a single illumination source (see fig. 6), so there's no need for multiple sources or for filters. Quantum dots don't fade like fluorescent dyes.

But there are enormous challenges in manufacturing quantum dots. A quantum dot is only two to six nanometers across. With its shell, coatings, and attached biomolecules in ready-to-use form, its diameter is ten to fifteen nanometers. Hundreds of millions of these ready-to-use quantum dots fit on the head of a pin. Quality control is challenging because manufacturers want the dots in each batch to have distinct, uniform color, but small size variations cause large color variations.

Many applications await cheap quantum dots, particularly for biological investigations. Several startups, including Evident Technologies (www.evidenttech.com), Nanoco, Ltd. (www.nanoco.biz), Nanosys, Inc. (www.nanosysinc.com), and Quantum Dot Corporation (www.qdots.com), are racing to develop high-volume manufacturing techniques.

It seems enough of a miracle to tag molecules with individual colors, but engineers at Quantum Dot have taken bar codes to the ultimate with "Qbeads." Qbeads mix quantum dots of different colors within a spherical latex bead. Mixing red, yellow, green, and blue quantum dots creates beads with unique spectral signatures. All of the colored quantum dots in the bead fluoresce when illuminated by a single laser. Spectral analysis of the emitted light reveals the Qbead's unique signature.

Suppose we mix beads in 10 percent increments and cataloged them with a number corresponding to the percent of each color. RYGB = 3205, for example, would be 30 percent red, 20 percent yellow, 0 percent green, and 50 percent blue. Catalog number 3205, which returns a unique spectral signature when illuminated, is just like a bar code. Four colors mixed to the nearest 10 percent build a catalog of almost three hundred unique bar codes. Mixing more colors in finer proportions yields thousands or millions of unique codes. Qbeads enable simultaneous testing of thousands of unknowns against a target molecule.

Lessons

UPCs are thirty years old and they're everywhere. Most of the items on my desk either have a bar code on them, or they came in a package that had a bar code on it. Bar codes and bar-code readers bridge physical items to online information.

The value of bar codes is immense. Imagine setting up a hardware store without them. The process would be error prone and labor intensive from item ordering, through inventory management, to checkout. Instead, the hardware store's big suppliers send their UPC-to-item-description catalogs. Armed with the catalogs' database, stockers scan arriving cases' bar codes to enter items into inventory. Checkers scan items' bar codes as customers buy them. The store's computer tracks inventory by netting arrivals against sales. The computer is the labor-saving workhorse for stocking levels, prices, reorder thresholds, lead times, order tracking, and dozens of other functions. This automation is enabled by the bar code's bridge between the physical item and the computer.

Optical bar codes proliferated before the Internet, which meant that shippers were only tenuously connected to their customers for information. With poor end-to-end informa-

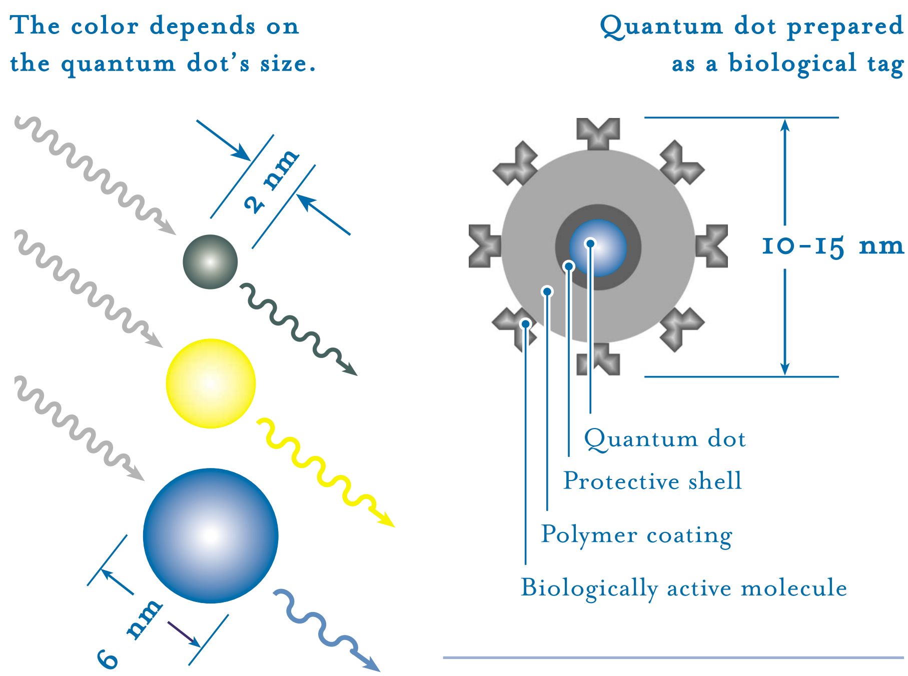


Fig. 6. Different sizes of semiconductor quantum dots emit different colors of light. Quantum dots can act as tags in biological experiments.

tion management (paper shipping documents), inventory management between the manufacturer and the customer—*the supply chain*—wasn't as easy to automate as *local* inventory management. UPCs automated local inventory management for the manufacturer and for the customer, but the supply chain was not automated.

The Internet provides the strong information connection between businesses that enables supply-chain automation. That's the incentive for increasing the information content of physical-item labeling to include a unique number per item. The combination of Internet connection for instant information flow and of tags with unique numbers enables tracking the entire life cycle of items, though security concerns may force the termination of tracking upon end-customer purchase.

Tag Scorecard

Attribute	UPC Bar Code	RFID Tag	IntelliDOT	Quantum Dot
Automated reading	No	Yes	No	No
Can be hidden	No	Yes	No	Maybe
Can be reprogrammed	No	Yes	No	No
Commercial availability	Yes	Yes	Yes	Developing
Computed responses	No	Yes	No	No
Fraud protection	No	Yes	Yes	Yes
Individual item numbers	No	Yes	Yes	Maybe
International standards	Yes	Developing	No	No
Line-of-sight required	Yes	No	Yes	Yes
OK for harsh environments	No	Yes	No	Yes
Read during rapid motion	No	Yes	No	No
Small-item labeling	No	No	Yes	Yes
Very low cost	Yes	No	Yes	No
Widely applied	Yes	Gaining	No	No

Passive RFID tags with an Electronic Product Code assign a unique number to each end item and have the advantage that they can be quickly read without human assistance. RFID tags are not restricted to line of sight. These two compelling advantages over optical tags ensure high-volume markets for RFID tags, at least in supply-chain applications. Today's RFID tags, even the cheapest, are too expensive to tag low-cost items. Fortunately, RFID tags are proving their value at the high end of the supply chain with shipping containers and with pallets. They increase productivity, efficiency, and product visibility from the manufacturer all the way to the customer. This decreases "shrinkage" and it reduces inventory requirements all along the supply chain. RFID tags will work their way down the chain as standards gain acceptance, as the cost of tags drops, and as readers get cheaper.

RFID tags below the shipping container and the pallet benefit the manufacturer *and* the store owner. The largest benefit to manufacturers and to store owners is in keeping shelves stocked so that the manufacturer's product gets to its ultimate customer. Store owners get better end-item availability (fewer empty shelves) with lower inventory. RFID tags will also reduce in-store inventory "shrinkage." According to a University of Florida survey, half of retail "shrinkage" is from employee theft and a third is from shoplifting. Once RFID tags make their way to individual consumer items, they will face tradeoffs between the advantages of individual tags and the desire for anonymity.

Below the market for RFID tags, there's opportunity for cheaply produced, information-packed optical codes in situations where small or consumable items require individual tracking.

Quantum dots extend the value of bar codes all the way down. Quantum dots, which add bar codes to *molecules*, will revolutionize drug development, biochemical analysis, and medical diagnostics.

UPCs, EPCs, intelliDOTs, quantum dots—there are applications and opportunities for all. The value that guarantees the success of optical and electronic bar codes from shipping containers to molecules is that bar codes complete the bridge to the physical world from the world of computers and the Internet.

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