Low Temperature Laser Processing Solves a Problem in Smart Materials Manufacturing

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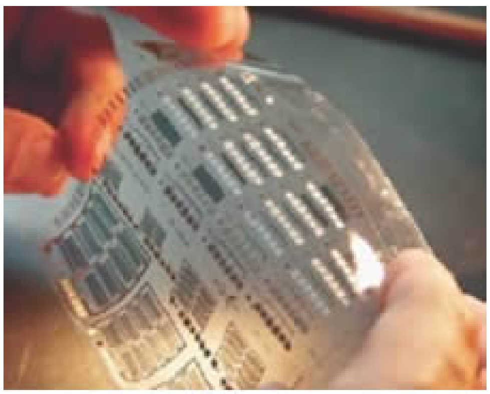

Flexible Microelectronics

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(PhysOrg.com) -- If researchers could integrate some of the active materials, such as perovskites, that have been developed in recent years for microsensor, actuator, and transducer applications directly onto a flexible polymer substrate or a CMOS integrated circuit, it would provide them with the ability to make new devices or shrink current electronics into smaller packages.

The problem is that in order to make these perovskite thin films highly functional, they must be crystallized, and that requires high temperatures. Polymers and computer chips can't withstand the kind of high temperature processing that crystallization requires. Prof. Susan Trolier-McKinstry and her group have been working on this seemingly intractable problem, one that researchers in the field of Random Access Memory have tried for ten years to solve without success. She believes Dr. Srowthi Bharadwaja, a research associate in her group, has come up with a viable solution at last, one that is ready to move up to an industrial scale with little delay.

Trolier-McKinstry is director of the W.M. Keck Smart Materials Integration Laboratory in the Materials Research Institute and leads the Center of Excellence in Piezoelectric Materials and Devices. Trolier-McKinstry and Srowthi Bharadwaja explained their breakthrough and its significance.

“The question is how to take materials with interesting properties that crystallize at 700 degrees C. and integrate them with substrates that can only stand temperatures of 200-400 degrees C. It’s hard to deposit a film of tunable dielectrics materials, or functional pyroelectrics or piezoelectrics on substrates and keep the substrate temperatures cold enough and still crystallize the film,” Trolier-McKinstry explained. Dielectric, pyroelectric, and piezoelectric effects are electrical properties found in many natural materials, such as perovskites, and refer to the ability to store electric charge, or to turn heat or strain into an electrical current or conversely, turn an electrical current into motion. These materials -- integrated into microelectromechanical systems -- have a wide variety of uses in miniature motors, antennas, auto focusing in digital cameras, and computer disk drives, among dozens of other common uses. The current market for piezoelectrics alone is estimated at more than $10 billion annually.

First success is infrared night vision

Using an excimer laser, the team annealed a lead-based ferroelectric thin film wafer that could be used for infrared night vision applications. Keeping substrate temperatures below 370 degrees C, they crystallized amorphous films with short laser pulses. One limitation of this system is that film thickness is limited to approximately ½ micron, depending on the material, in order to get the thermal pulse deep enough to crystallize the entire film.

“We use excimer laser pulses of 20 nanoseconds,” Bharadwaja elaborated. “We defocus the energy on top of the samples, thereby heating the film locally without overheating the substrate. This is the basic principal, but because the development of electroceramic thin films is relatively recent, and we don’t fully understand the relationship among device structure, processing, and materials properties, we also have to fine tune a lot of the laser parameters, the gas ambience, and also the energy density. That’s important for scaling up for industrial use.”

Trolier-McKinstry added, “The process can also run using a high powered infrared laser, which is widely used in industry. Instead of focusing the energy so that it creates a plasma, we spread the energy across a wide area, staying below the threshold that you would use to oblate material.”

Solving scientific and industry problems

Understanding how materials crystallize is not easy when samples are annealed in a furnace over a period that can vary from seconds to hours. The speed of laser annealing makes the study of the kinetics of crystallization more precise. “The calculations that Bharadwaja is doing show that you really can crystallize material in under 10 milliseconds, so now we’re beginning to study regimes that were never accessible before,” Trolier-McKinstry said. There are many more crystallization studies to perform before the most important questions are answered. “Maybe in a year we’ll have the answers,” she said.

The ability to crystallize thin films with lasers is of interest to a number of industries, including semiconductor manufacturers, night vision equipment makers, the computer memory industry, and integrated passive component makers. Some companies would like to be able to put better capacitors onto the printed circuit boards that are the heart of computers and cell phones. These small green boards, called FR4 boards, are already so jammed with components that it is difficult to shrink them further. One solution would be to put the capacitors on a flexible material that could be laminated one on top of the other and then buried inside the board. Something of the sort is already being pursued at DuPont using high temperature dielectrics on metal foil, but the Penn State method could expand this solution to polymers.

The ability to crystallize a pyroelectric film on a camera lens or goggles is an obvious plus for infrared imaging, inasmuch as pyroelectric materials respond to heat with an electrical response. Two companies in the night vision industry (Bridge Semiconductors and L3 Inc) have shown an interest in this application of the technology. There is also pending intellectual property protection for a microelectromechanical systems (MEMS) application. Ultrasonic guidance systems for robots is yet another possible use.

The path to implementation

Unlike much of the technologies that come out of university labs, Bharadwaja’s laser processing approach would seem to be a good fit for industry. The technology for amorphous film deposition is nearly universally available, and many companies already use lasers suitable for annealing. Several companies associated with Penn State’s Center for Dielectric Studies, which sponsored the research, are quite interested. However, Trolier-McKinstry is cautious about predicting how laboratory breakthroughs will ultimately fare in the marketplace. “It’s important to realize that whether or not this gets implemented in industry depends not just on the technology of making the film, it really depends on the whole system. Does the manufacturing system require the integration of the active oxide materials on a low temperature substrate? If so, we're providing a piece for the system, but how fast it is adopted by industry is going to depend more on the entire system design than on this particular part of the technology."

The next step

Bharadwaja continues to refine the technology in his lab, trying out new materials and substrates to understand the crystallization phenomenon in laser annealing, and finding ways to make processing faster. Already he has completely crystallized a 6" wafer in one hour and ten minutes, about half the time that industry had given him as a target. He thinks he can improve on that time with new techniques.

Walking to his lab he explained their next step. "What we are looking at is doing the laser annealing during the deposition process itself. That way we can reduce the time and processing cost, and also improve scaling up for industry. This should also allow industry to process films thicker than ½ micron."

Taking inventions from the university to the marketplace is always a roll of the dice. "That's something that is out of our control," Trolier-McKinstry acknowledged. But after 10 years of effort, this technology is beginning to look like a pretty good bet.

Provided by Penn State

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